Physics Colloquium

سخنرانی عمومی فیزیک

پژوهشگاه دانش‌های بنیادی (مرکز تحقیقات فیزیک نظری و ریاضیات)

IPM

INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES

Wednesday 27 Farvardin 1404 (16 April 2025)

Copenhagen Survey on Black Holes and Fundamental Physics

Niayesh Afshordi

UNIVERSITY OF WATERLOO

CONCORDIA CUM VERITATE

WATERLOO CENTRE FOR ASTROPHYSICS

WCA

25 YEARS

PERIMETER INSTITUTE

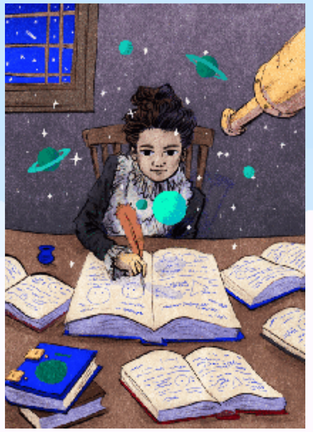
arXiv > gr-qc > arXiv:2503.15776

General Relativity and Quantum Cosmology

[Submitted on 20 Mar 2025 (v1), last revised 26 Mar 2025 (this version, v2)]

Copenhagen Survey on Black Holes and Fundamental Physics

Alice Y. Chen, Phil Halper, Niayesh Afshordi



- The results of a unique survey conducted at the 2024 workshop **‘Black Holes Inside and Out’** held in Copenhagen.
- Capture the views of leading physicists (both junior and senior, from diverse backgrounds) on deep open questions in black holes and fundamental physics.
- Snapshot of current thinking in the community on issues that remain unresolved in theoretical and observational physics.

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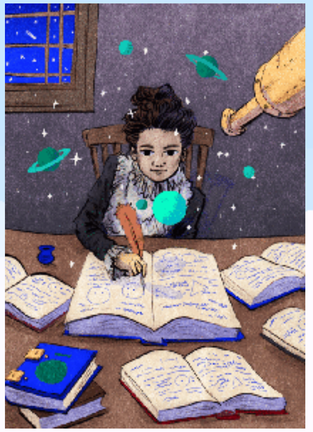

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BLACK HOLES
INSIDE AND OUT

Niels Bohr Institute
Copenhagen
26–30 August 2024

Program

The scientific program is as follows:

Day 1. Aug 26: Classical Black holes +

Day 2. Aug 27: Black holes beyond General Relativity +

Day 3. Aug 28: Black holes as laboratories: tests of General Relativity +

Day 4. Aug 29: Testing the black hole paradigm +

Day 5. Aug 30: Quantum black holes −

Morning chair: Tomohiro Harada

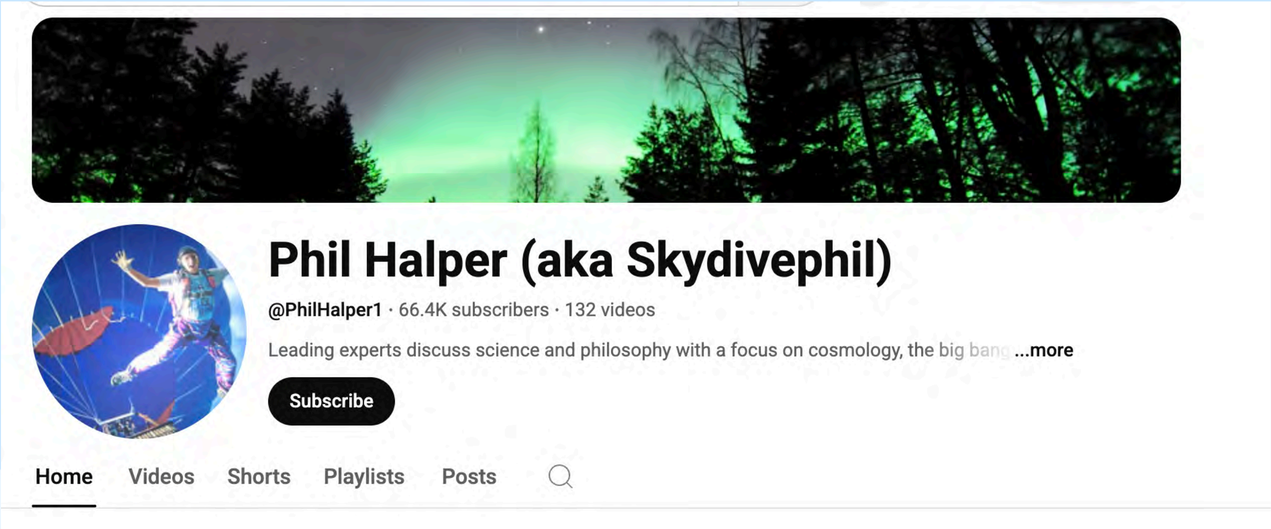
08:00-08:45 Coffee/tea/light breakfast
08:45-09:40 Alessia Platania, on gravitational collapse and singularity resolution in asymptotic safety - slides
09:40-10:10 Coffee Break
10:10-11:05 Abhay Ashtekar, on black holes and singularity resolution in LQG - slides
11:05-12:00 Samir Mathur, on the fuzzball paradigm and black holes in string theory - slides
12:00-14:00 Lunch (please find your own)

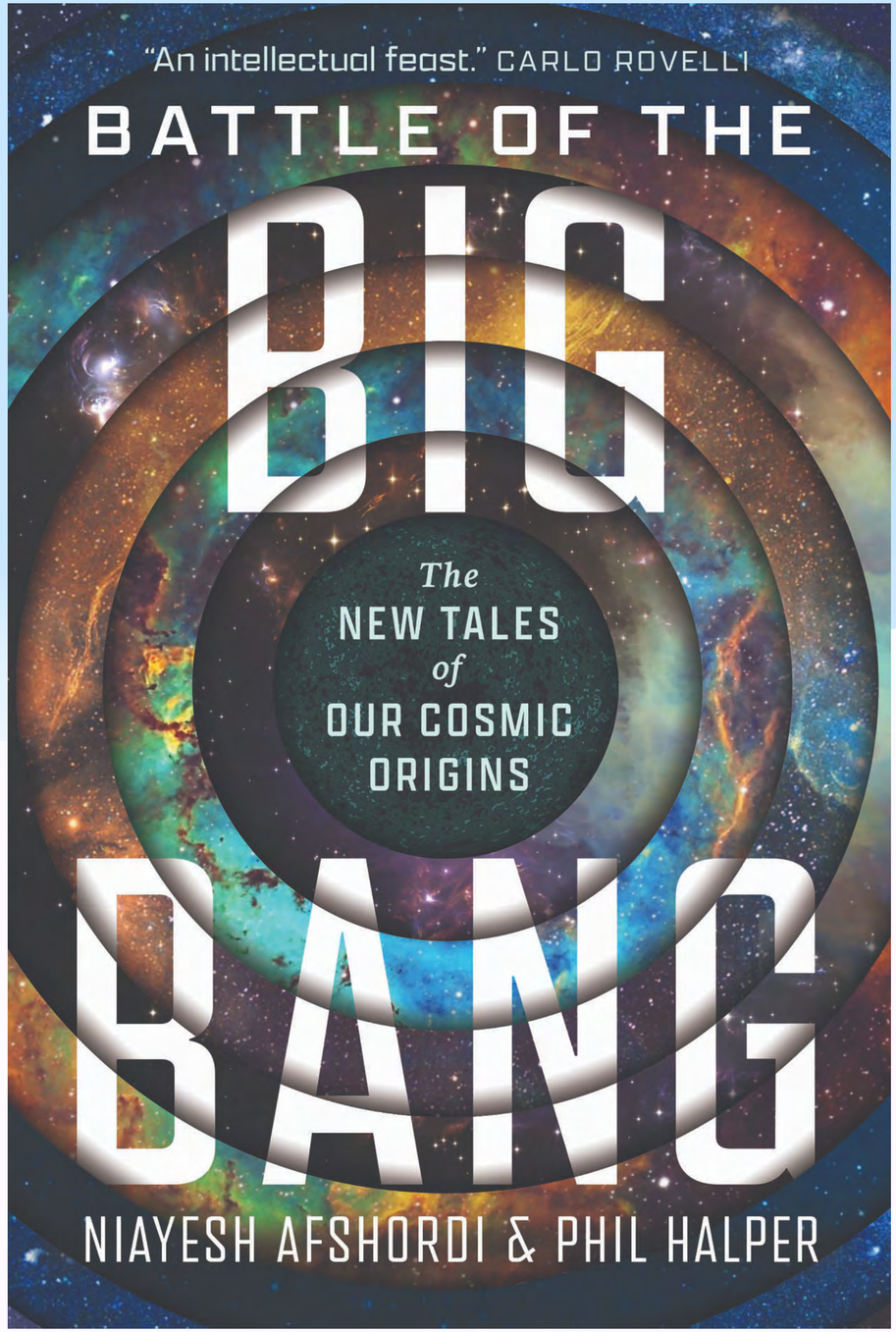
Afternoon chair: Vitor Cardoso
14:00-14:55 Netta Engelhardt, on holographic approach to black holes
14:55-15:55 Round Table with Niayesh Afshordi and Stefano Liberati - slides
15:55-17:00 Poster winner + Farewell + Social Coffee - slides

Invited Speakers

Niayesh Afshordi
Abhay Ashtekar
Enrico Barausse
Emanuele Berti
Richard Brito
Alessandra Buonanno
Gregorio Carullo
Mihalis Dafermos
Mariafelicia de Laurentis
Adrián del Rio
Roberto Emparan
Netta Engelhardt
Stefan Gillessen
Ruth Gregory
Carlos Herdeiro
Tanja Hinderer
Jutta Kunz
Luis Lehner
Stefano Liberati
Samir Mathur
Ramesh Narayan
Samaya Nissanke
Paolo Pani
Alessia Platania
Eric Poisson
Frans Pretorius
Misao Sasaki
Paul Tiede
Will Unruh
Matt Visser
Bob Wald
Helvi Witek

How I met Phil!





Current Topics within Physics
Survey of Participants
Black Holes Inside and Out Conference, Copenhagen 2024

Purpose

With the conference being an especially large gathering of physicists, we see a rare opportunity to survey professionals on their opinion on current topics within the field. This will be a helpful snapshot of current thinking on cutting edge questions which we believe will be useful to sociologists and historians of science in understanding how scientific opinion changes over time. Given enough replies, the results will be published on the arxiv and submitted to a peer reviewed journal.

Authors

Niayesh Afshordi: Niayesh is a professor in the Astrophysics and Gravitation group at the Department of Physics and Astronomy, University of Waterloo and a founding faculty member at the Waterloo Centre for Astrophysics. He is also an Associate Faculty in the Cosmology and Gravitation group at the Perimeter Institute for theoretical Physics.

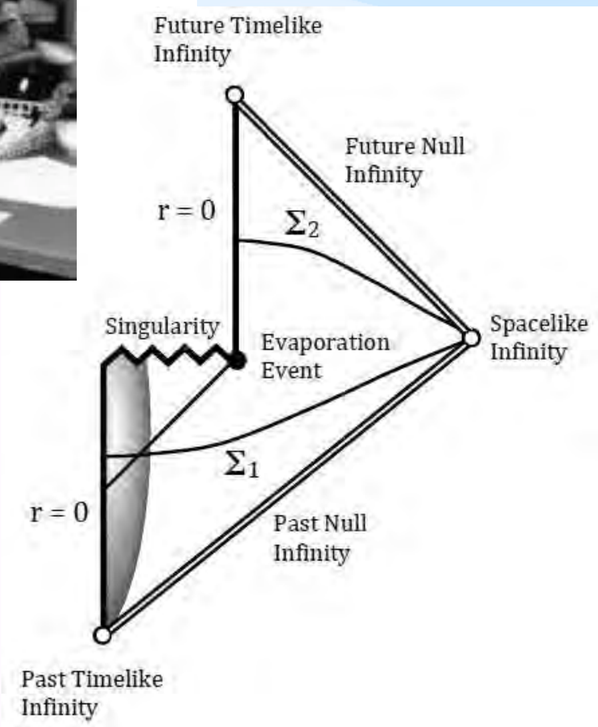
Phil Halper: Phil is an independent science communicator, Fellow of the Royal Astronomical Society, London and 2019 Journalist in Residence at the Penn State Institute for Gravitation and the Cosmos. Phil has published several papers in peer reviewed journals and has interviewed many of the world's leading physicists including Stephen Hawking, Roger Penrose, Rai Weiss and numerous others.

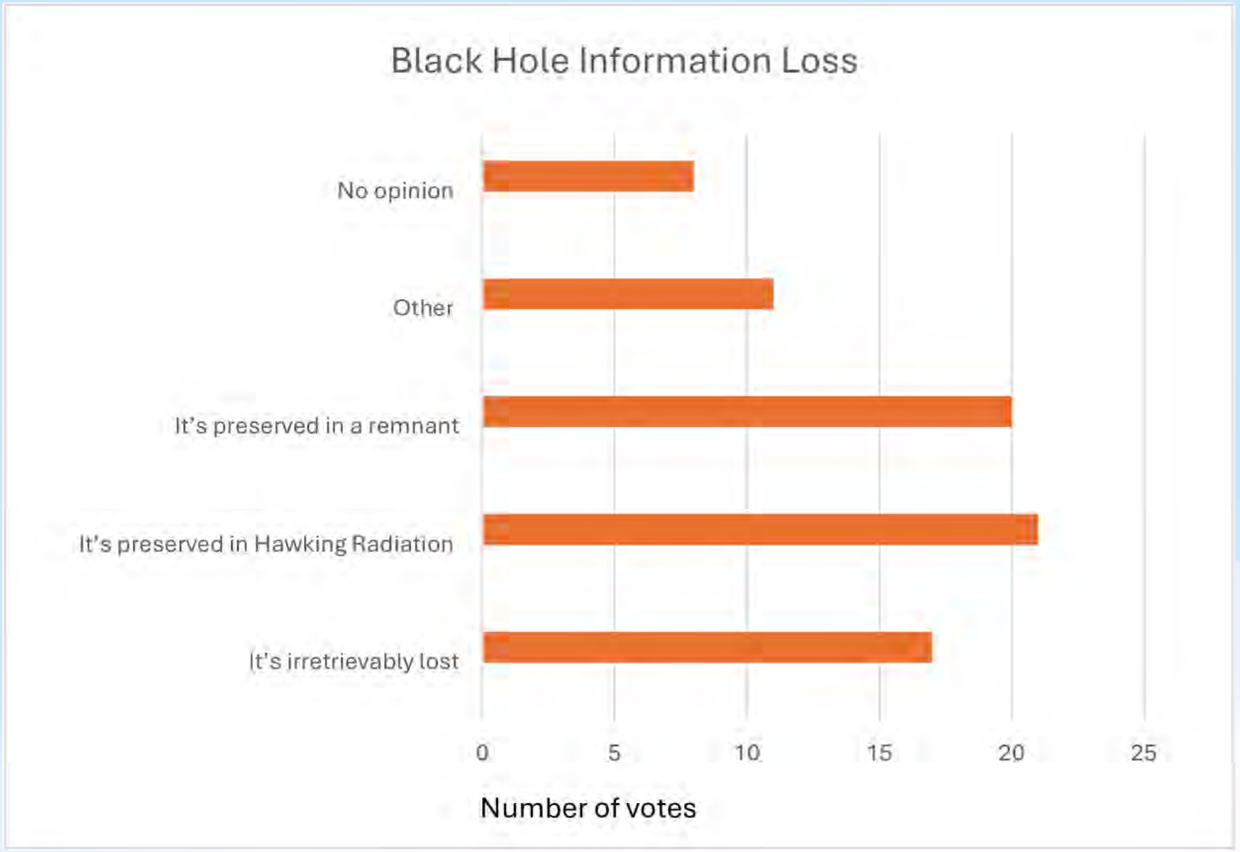
85 completed surveys from 151 registered participants

1. *Information Paradox*

In your opinion, what do you think is the most likely correct description of the information that falls into a black hole?

- ☐ It's irretrievably lost
- ☐ It's preserved in Hawking Radiation
- ☐ It's preserved in a remnant
- ☐ Other
- ☐ No opinion





Answer Option	Number of Votes	Percentage
It's irretrievably lost	17	22 %
It's preserved in Hawking Radiation	21	27 %
It's preserved in a remnant	20	26 %
Other	11	14 %
No opinion	8	10 %
Total	77	100%

Table 1: In your opinion, what do you think is the most likely correct description of the information that falls into a black hole?

<<back

50 years of the black hole information paradox: October 6 – November 21, 2025

February 3, 2025 by Janell Rodgers

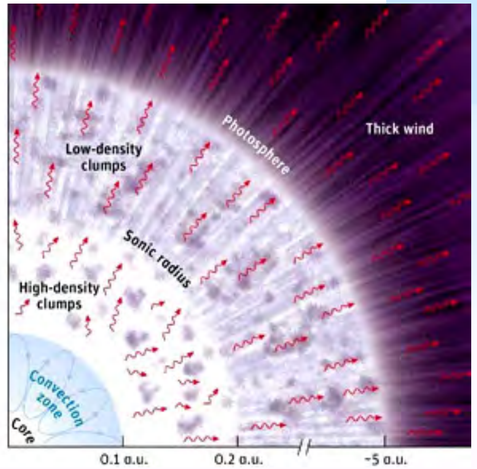
Organized by: Niayesh Afshordi, Emil Martinec and Samir D. Mathur

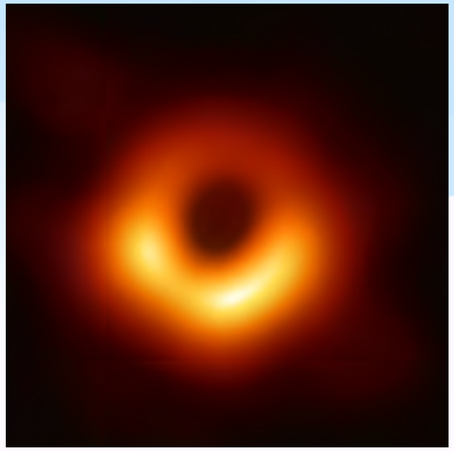
50 years ago Stephen Hawking published his famous paper arguing that the evaporation of black holes violated quantum unitarity. In the intervening decades, the puzzle, known as the black hole information paradox, has become an intense focus of interest. Yet different parts of the physics community hold very disparate views on the resolution of the paradox. In approaches using canonically quantized Einstein gravity, information is typically lost, stored in baby universes or leaking out slowly in long lived remnants. In string theory, on the other hand, there is considerable evidence that the information should come out in Hawking radiation, just as it does in the radiation from a normal body. The explicit constructions of black hole microstates as fuzzballs have provided a potential resolution of the puzzle. Yet other approaches have argued that wormholes can be relevant to understanding the black hole geometry and dynamics.

2. *Super Massive Black Holes*

In your opinion what is the most likely scenario for the creation of super massive black holes?

- ☐ Primordial black hole seeds
- ☐ Direct collapse seeds
- ☐ Super-Eddington accretion into stellar seeds
- ☐ Sub-Eddington accretion into stellar seeds
- ☐ Other
- ☐ No opinion





$$L_{\rm Edd} = \frac{4\pi G M m_{\rm p} c}{\sigma_{\rm T}}$$
$$\cong 1.26 \times 10^{31} \left(\frac{M}{M_\odot}\right) \mathrm{W} = 1.26 \times 10^{38} \left(\frac{M}{M_\odot}\right) \mathrm{erg/s} = 3.2 \times 10^{4} \left(\frac{M}{M_\odot}\right) L_\odot$$

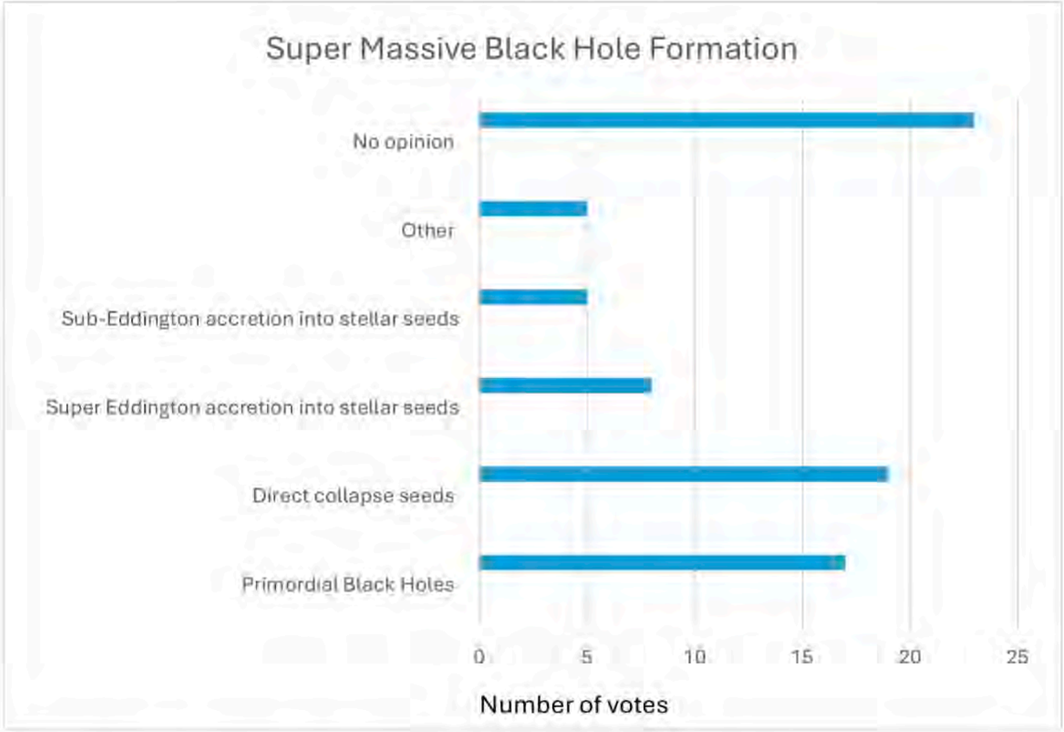


Figure 2: In your opinion, what is the most likely scenario for the creation of supermassive black holes?

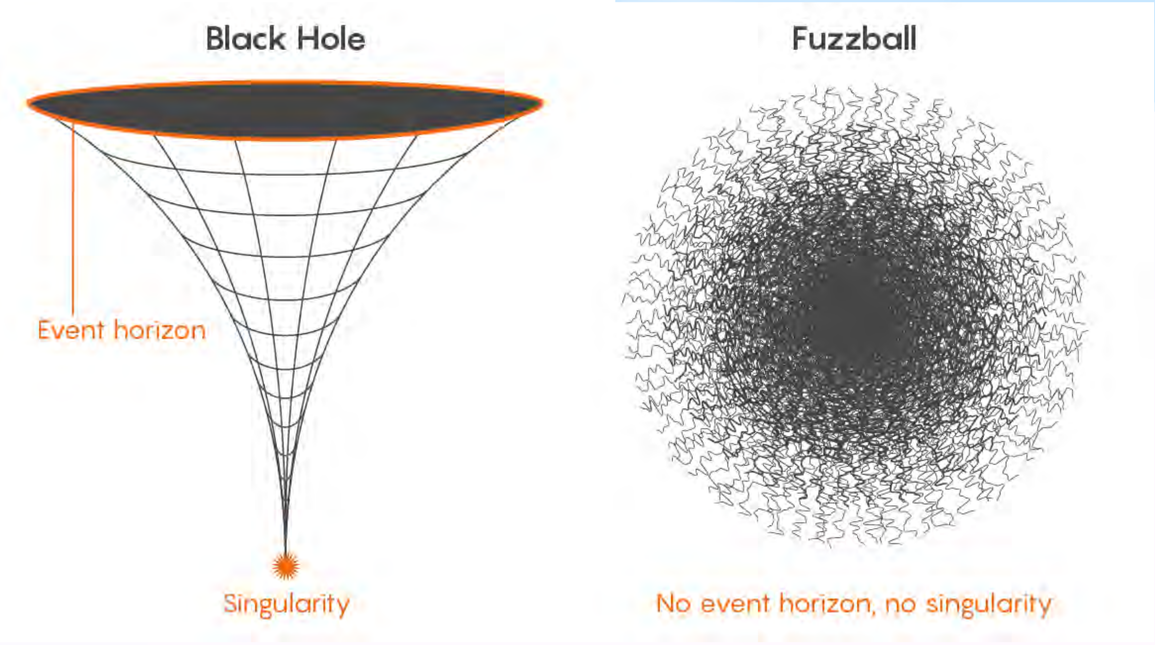
Answer Option	Number of Votes	Percentage
Primordial Black Holes	17	22 %
Direct collapse seeds	19	25 %
Super Eddington accretion into stellar seeds	8	10 %
Sub-Eddington accretion into stellar seeds	5	6 %
Other	5	6 %
No opinion	23	30 %
Total	77	100%

Table 2: In your opinion, what is the most likely scenario for the creation of supermassive black holes?

3. *Fate of Matter Inside a Black Hole*

In your opinion, what is likely to happen to the matter that falls into a black hole?

- ☐ It is crushed into a singularity
- ☐ It becomes a fuzzball
- ☐ It bounces out into our universe
- ☐ It bounces out into another universe
- ☐ Other
- ☐ No opinion



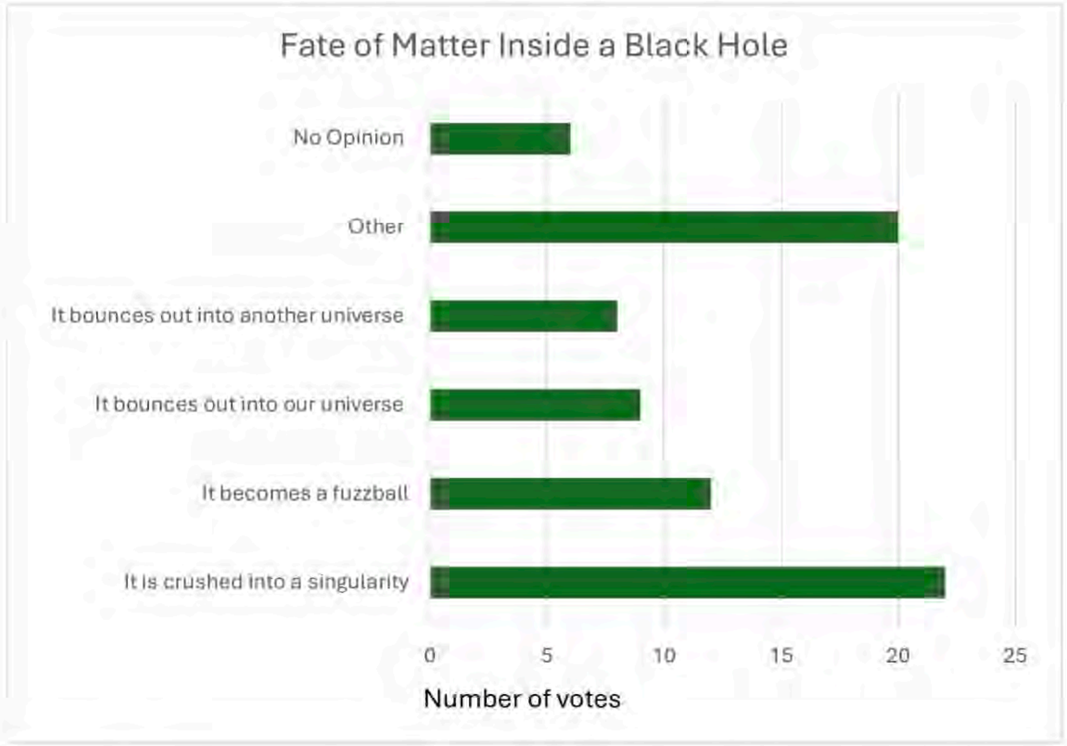


Figure 3: In your opinion, what is likely to happen to the matter that falls into a black hole?

Answer Option	Number of Votes	Percentage
It is crushed into a singularity	22	29 %
It becomes a fuzzball	12	16 %
It bounces out into our universe	9	12 %
It bounces out into another universe	8	10 %
Other	20	26 %
No Opinion	6	8 %
Total	77	100%

Table 3: In your opinion, what is likely to happen to the matter that falls into a black hole?

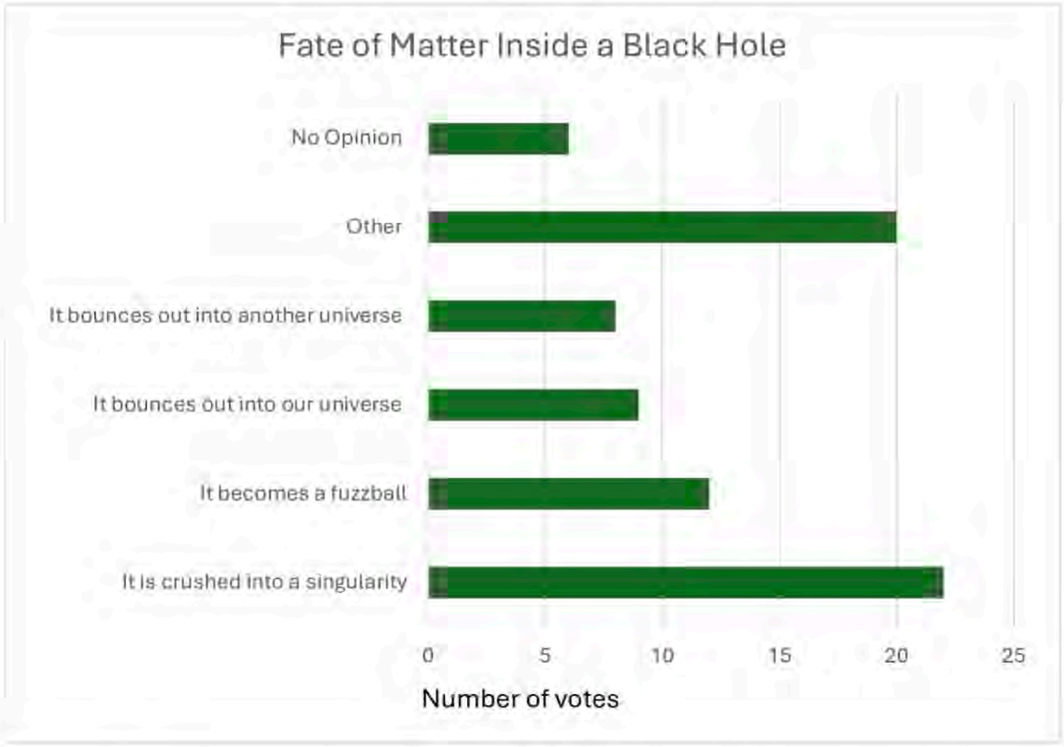


Figure 3: In your opinion, what is likely to happen to the matter that falls into a black hole?

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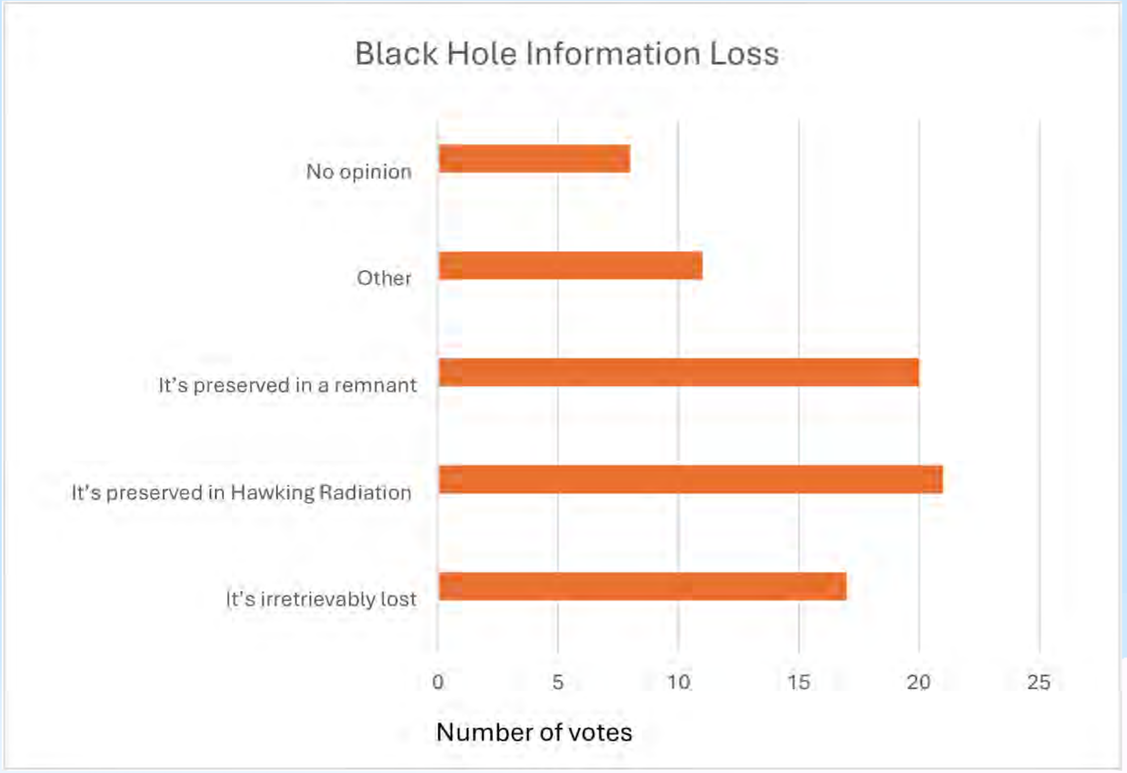
It becomes a fuzzball	12	16 %
It bounces out into our universe	9	12 %
It bounces out into another universe	8	10 %
Other	20	26 %
No Opinion	6	8 %
Total	77	100%

Table 3: In your opinion, what is likely to happen to the matter that falls into a black hole?



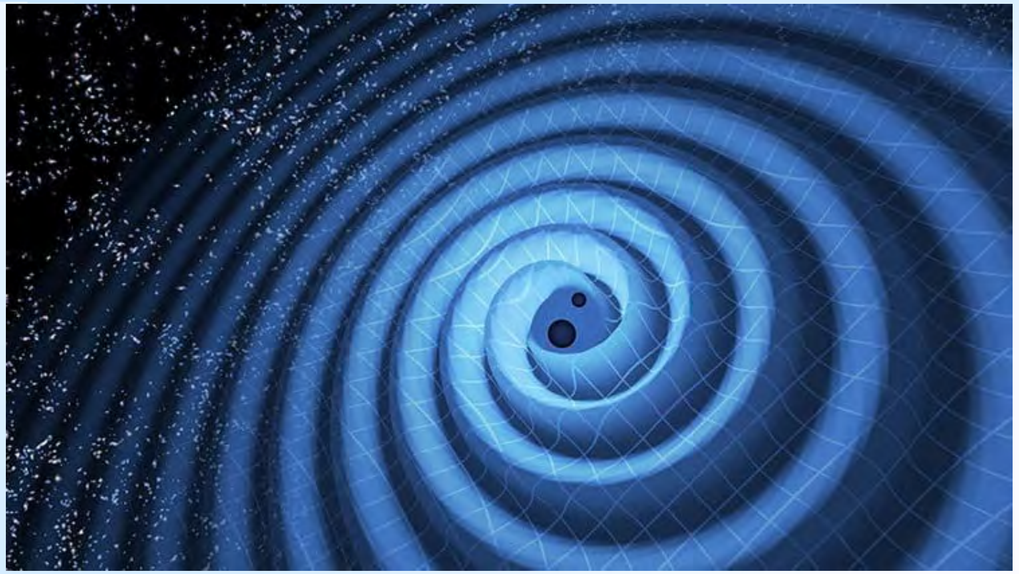
Answer Option	Number of Votes	Percentage
It's irretrievably lost	17	22 %
It's preserved in Hawking Radiation	21	27 %
It's preserved in a remnant	20	26 %
Other	11	14 %
No opinion	8	10 %
Total	77	100%

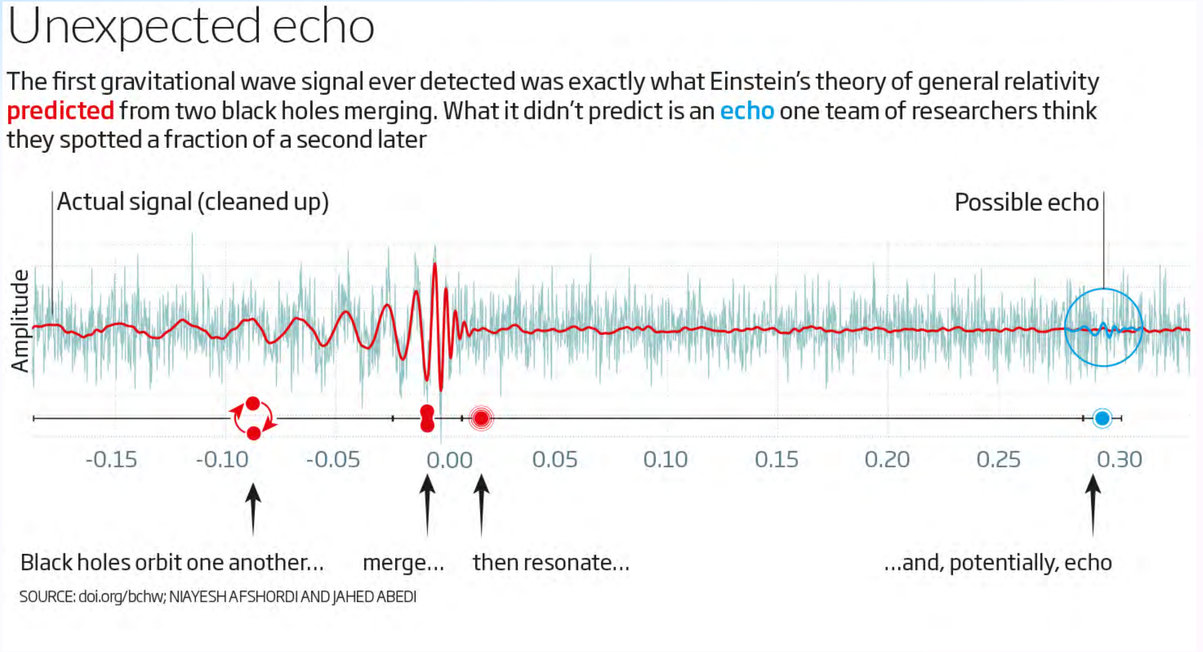
Table 1: In your opinion, what do you think is the most likely correct description of the information that falls into a black h

4. *Testing Quantum Gravity with Black Holes*

In your opinion, what are the most promising observable signatures of quantum gravity in black holes?

- ☐ Black hole shadows are not full dark
- ☐ Effective Field Theory corrections to inspiral/ringdown
- ☐ Gravitational Wave Echoes
- ☐ Deviations from Kerr Spacetime multipoles
- ☐ Other
- ☐ No opinion





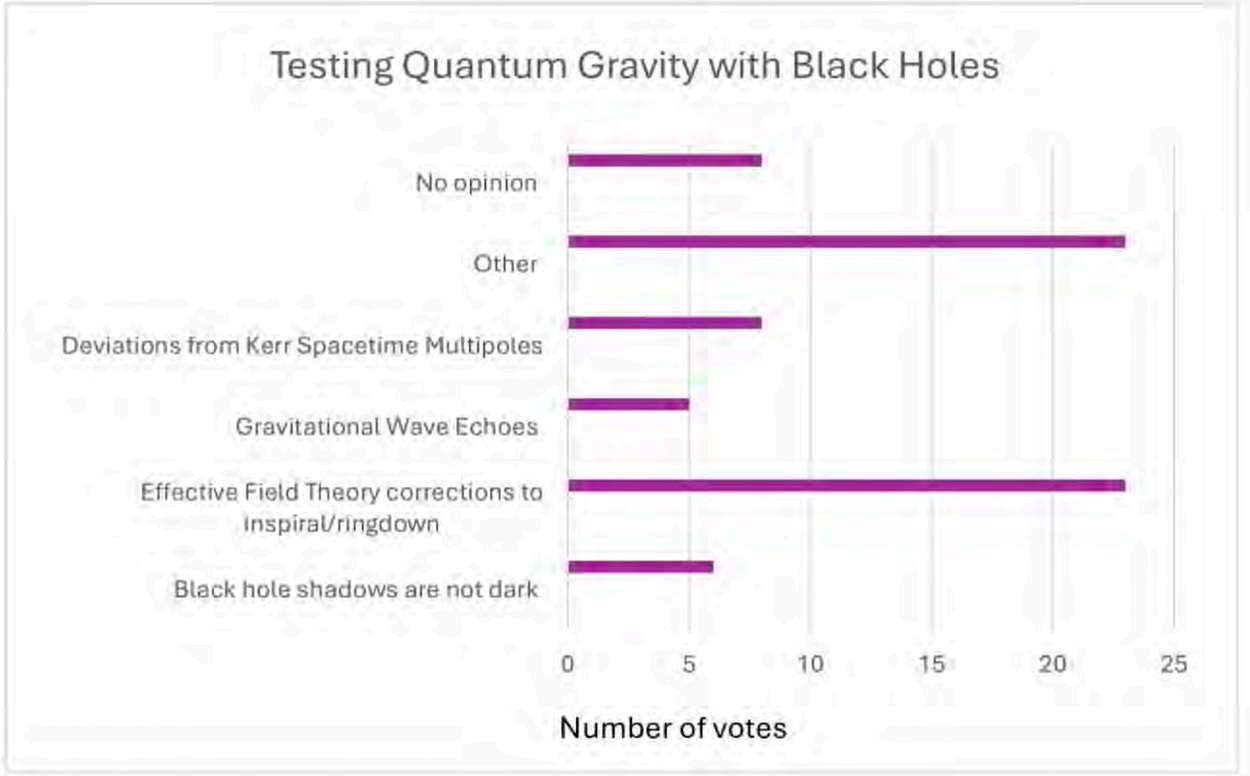


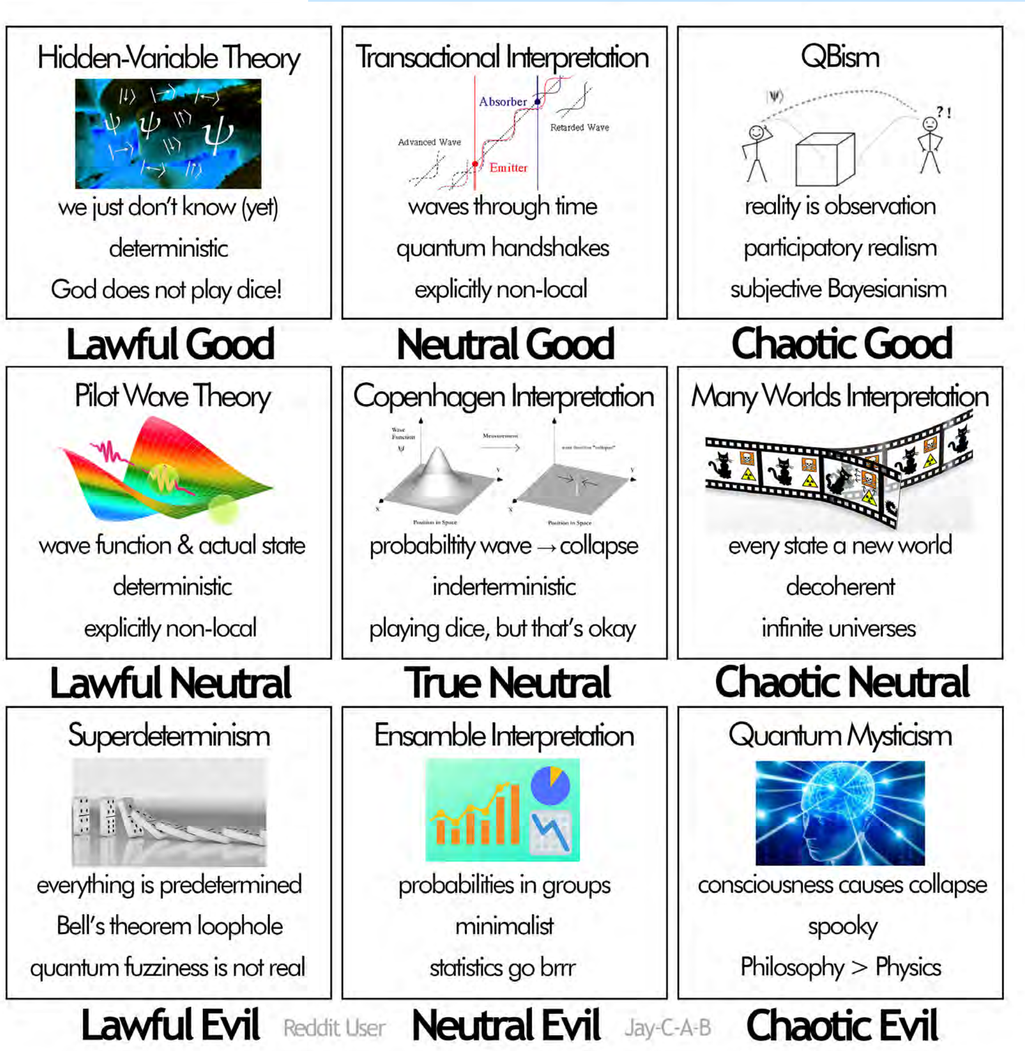
Figure 4: In your opinion, what are the most promising observable signature of quantum gravity in black holes?

Answer Option	Number of Votes	Percentage
No opinion	8	11 %
Other	23	32 %
Deviations from Kerr Spacetime Multipoles	8	11 %
Gravitational Wave Echoes	5	7 %
Effective Field Theory corrections to inspiral/ringdown	23	32 %
Black hole shadows are not dark	6	8 %
Total	73	100%

5. *Interpretations of Quantum Mechanics*

In your opinion, which interpretation of quantum mechanics is most likely to be correct?

- ☐ Copenhagen
- ☐ Many Worlds
- ☐ Qbism
- ☐ Pilot Wave/de Broglie Bohm
- ☐ Collapse Theories
- ☐ Consistent Histories
- ☐ Other
- ☐ No opinion



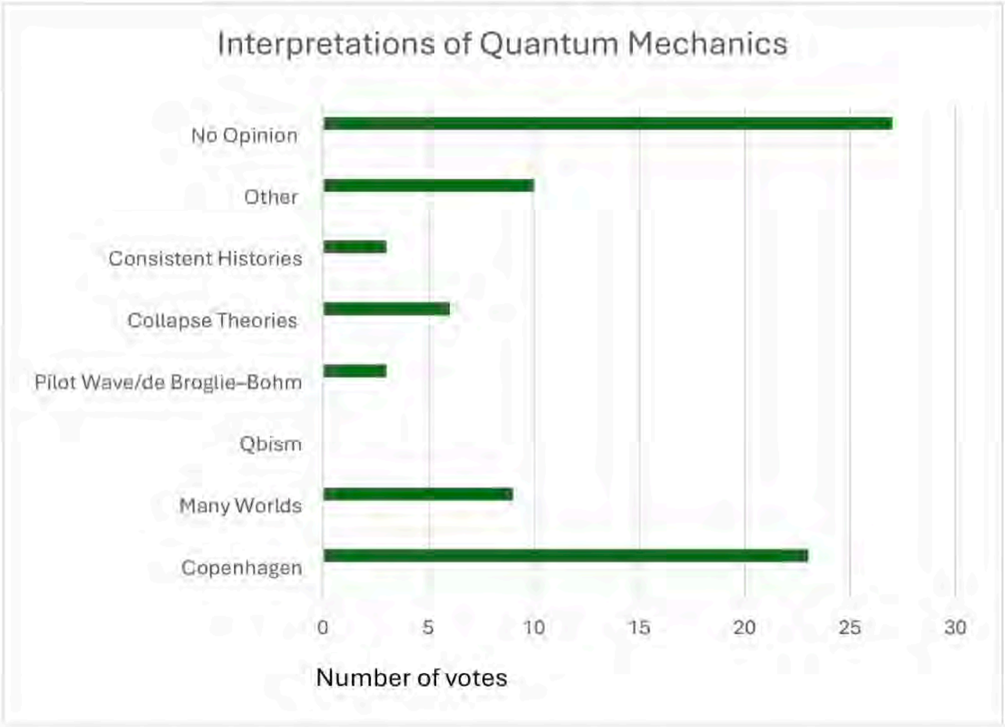


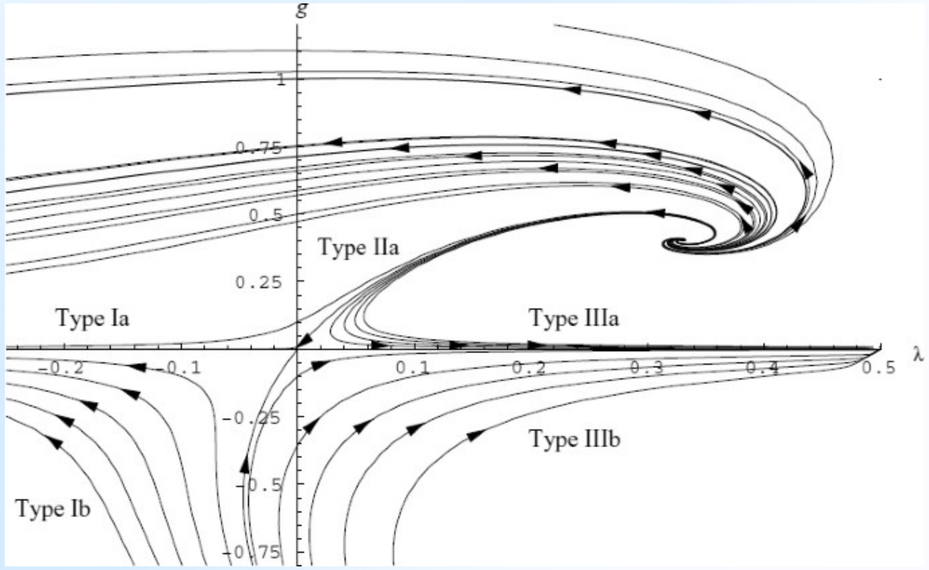
Figure 5: In your opinion, which interpretation of quantum mechanics is most likely to be correct?

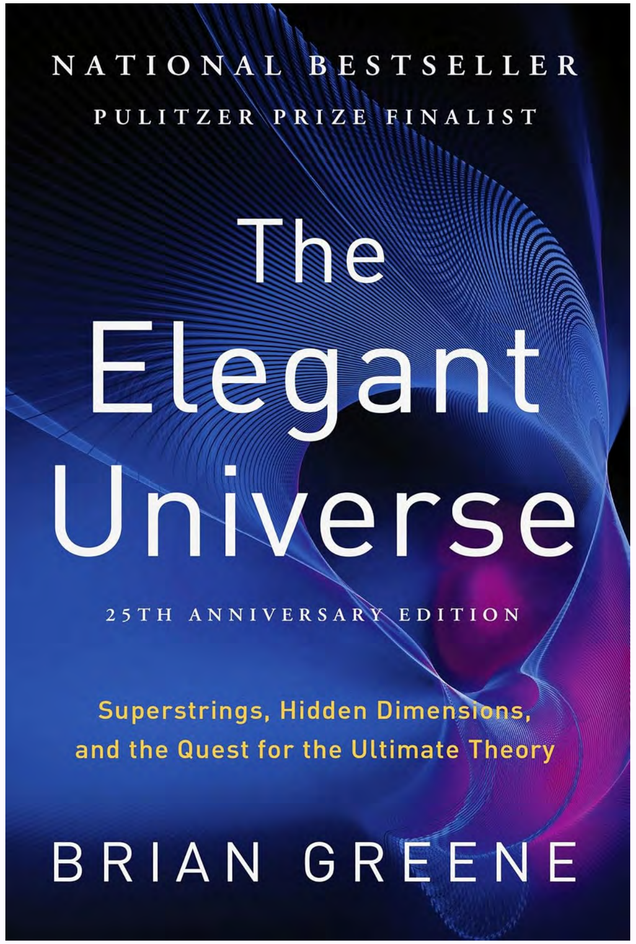
Answer Option	Number of Votes	Percentage
Copenhagen	23	28 %
Many Worlds	9	11 %
Qbism	0	0 %
Pilot Wave/de Broglie-Bohm	3	4 %
Collapse Theories	6	7 %
Consistent Histories	3	4 %
Other	10	12 %
No Opinion	27	33 %
Total	81	100%

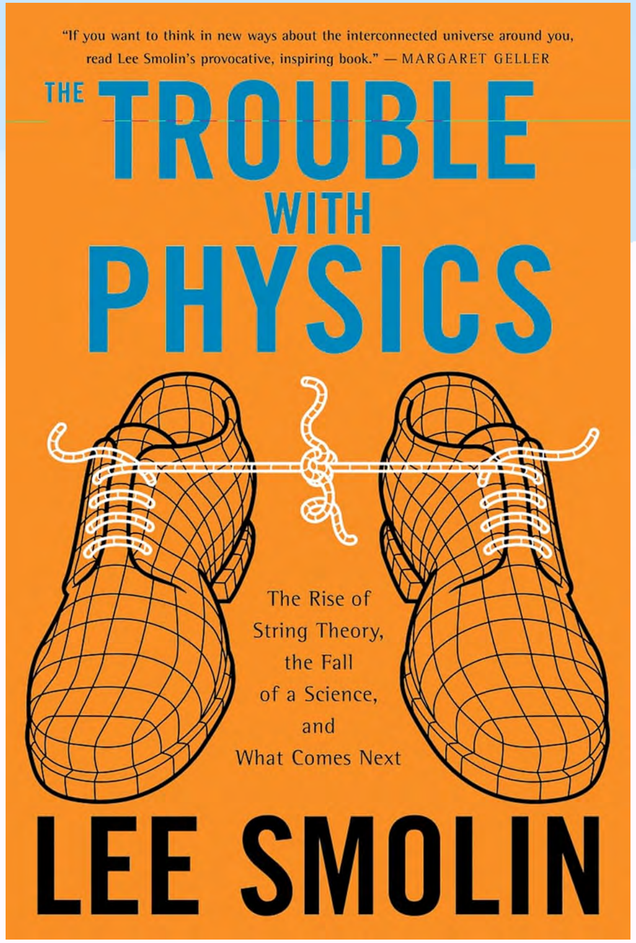
6. *Quantum Gravity*

In your opinion, which is the best candidate for a theory of quantum gravity?

- ☐ String/M Theory
- ☐ Loop Quantum Gravity
- ☐ Causal Sets
- ☐ Hořava–Lifshitz Gravity
- ☐ Causal Dynamic Triangulations
- ☐ Asymptomatic Safety
- ☐ Gravity is not quantum
- ☐ Other
- ☐ No opinion







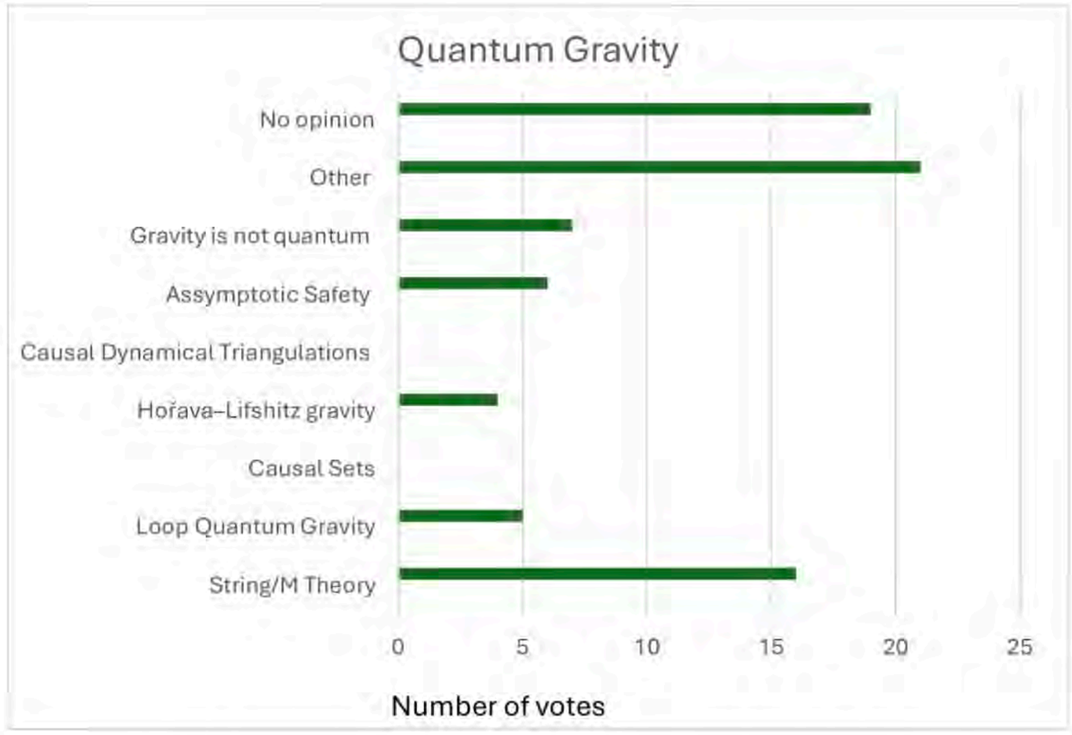


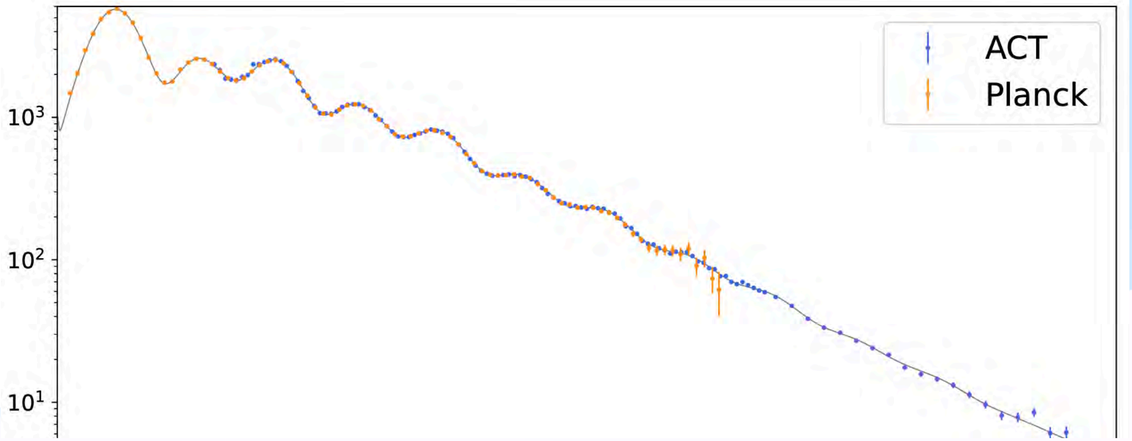
Figure 6: In your opinion, which the best candidate for a theory of quantum gravity?

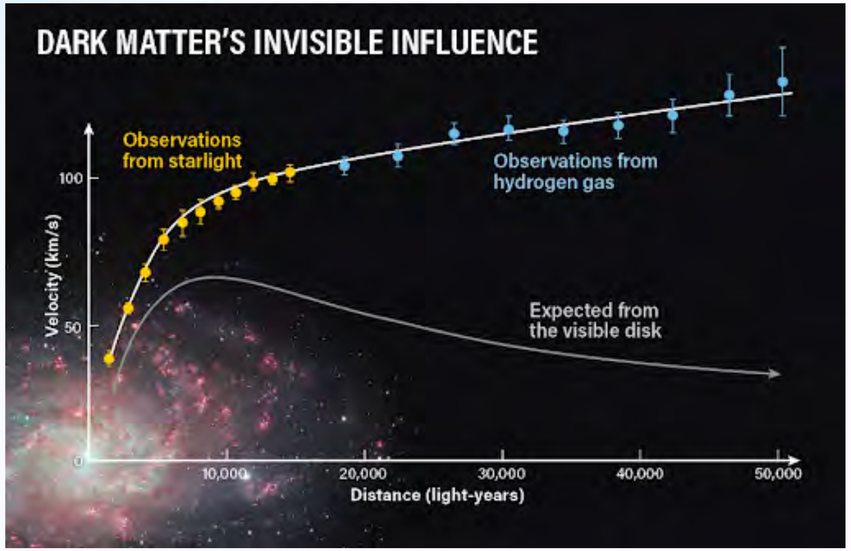
Answer Option	Number of Votes	Percentage
String/M Theory	16	21 %
Loop Quantum Gravity	5	6 %
Causal Sets	0	0 %
Hořava–Lifshitz gravity	4	5 %
Causal Dynamical Triangulations	0	0 %
Asymptotic Safety	6	8 %
Gravity is not quantum	7	9 %
Other	21	27 %
No opinion	19	24 %
Total	78	100 %

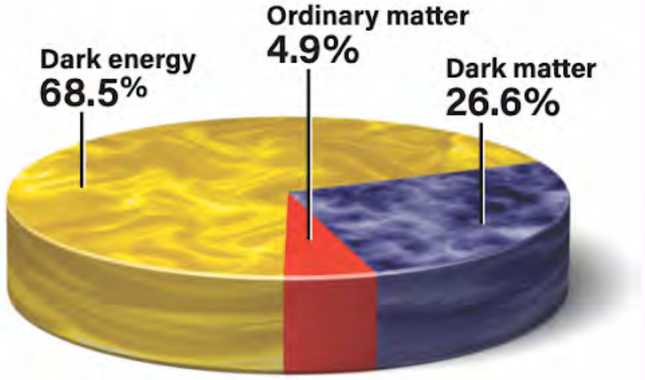
7. *Dark Matter*

In your opinion, what is likely to be the predominant explanation for the apparent dark matter in the universe?

- ☐ Light particle dark matter (e.g.. axions)
- ☐ Heavy particle dark matter (e.g., WIMPs)
- ☐ Some form of modified gravity
- ☐ Primordial black holes
- ☐ Some hybrid of the above
- ☐ Effect of quantum gravity
- ☐ Other
- ☐ No opinion







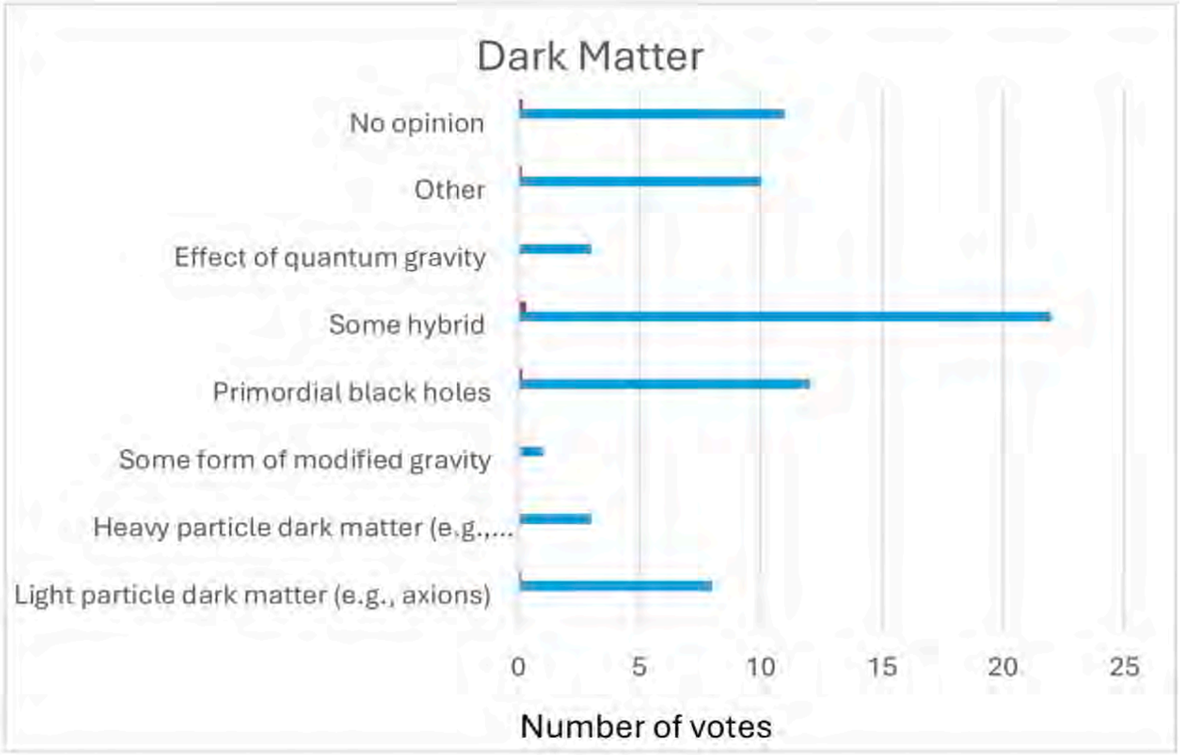


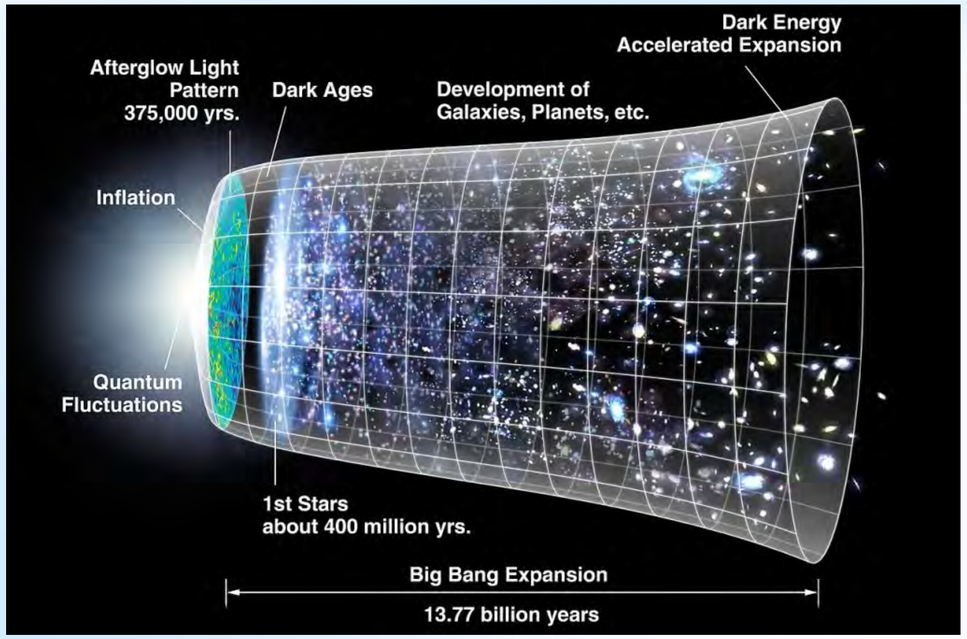
Figure 7: In your opinion, what is likely to be the predominant explanation for the apparent dark matter in the universe?

Answer Option	Number of Votes	Percentage
Light particle dark matter (e.g., axions	8	11%
Heavy particle dark matter (e.g., WIMPs)	3	4%
Some form of modified gravity	1	1%
Primordial black holes	12	17%
Some hybrid of the above	22	31%
Effect of quantum gravity	3	4 %
Other	10	14%
No opinion	11	16%
Total	70	100 %

8. *Early Universe Cosmology*

In your opinion, issues such as the horizon problem, flatness, and origin of structure problem are most likely solved by which scheme?

- ☐ Cosmic Inflation
- ☐ A bouncing or cyclic universe
- ☐ Some quantum gravity model
- ☐ Breakdown of Lorentz invariance
- ☐ Not inflation but don't have an alternative
- ☐ Other
- ☐ No opinion



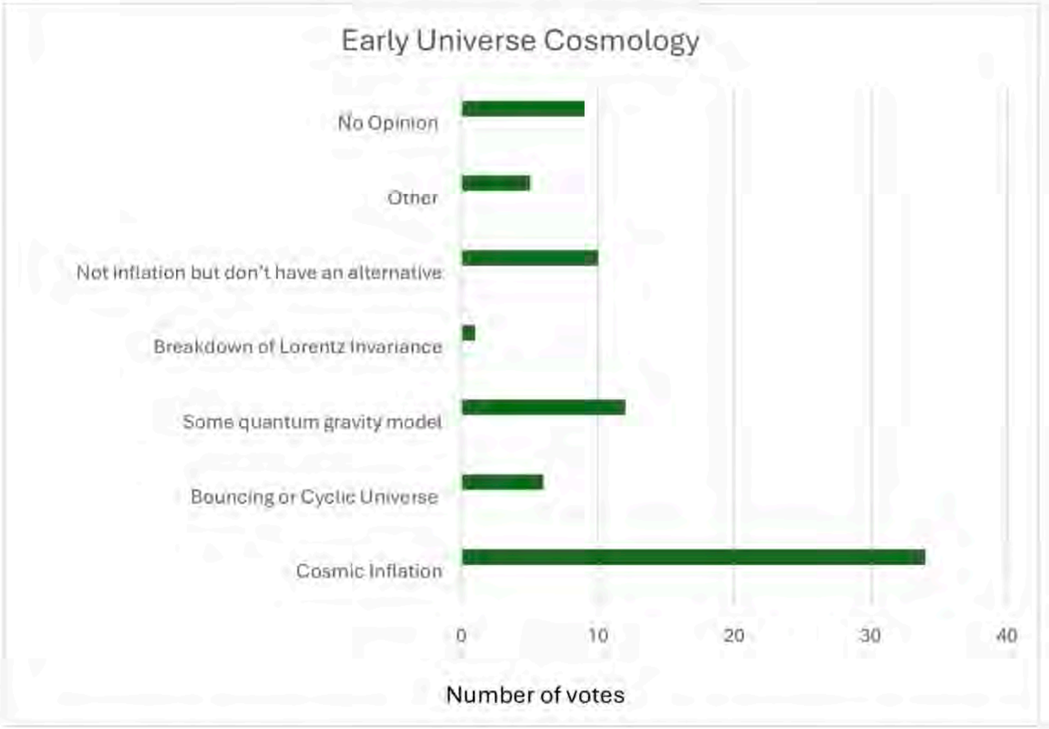


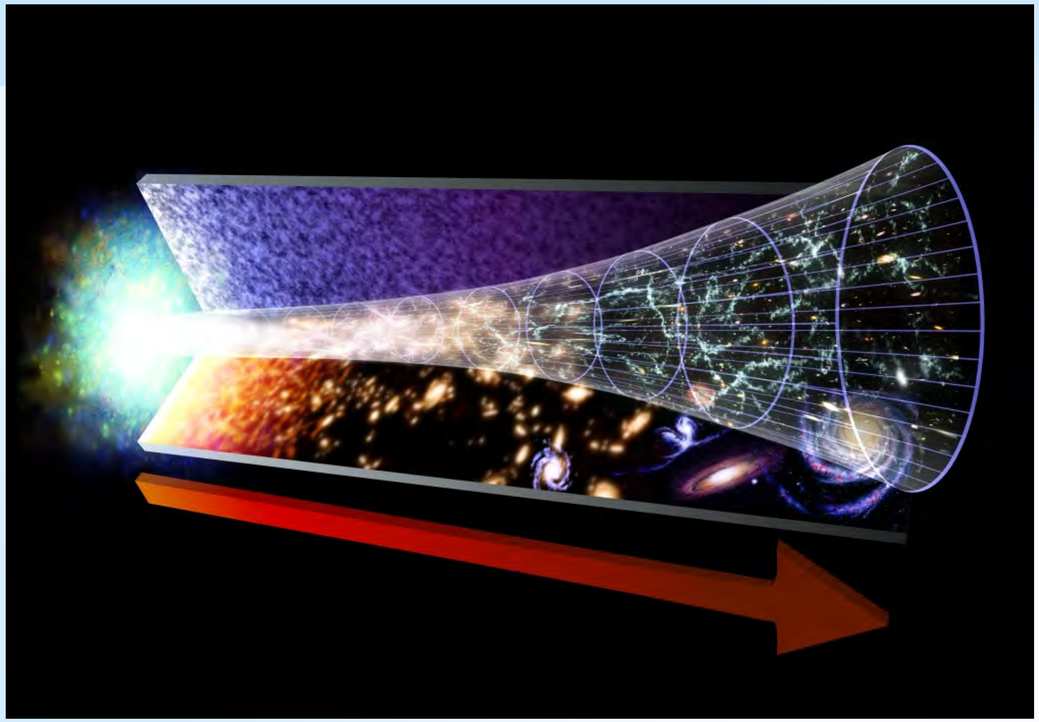
Figure 8: In your opinion, issues such as the horizon problem, flatness, and origin of structure problem are most likely solved by which scheme?

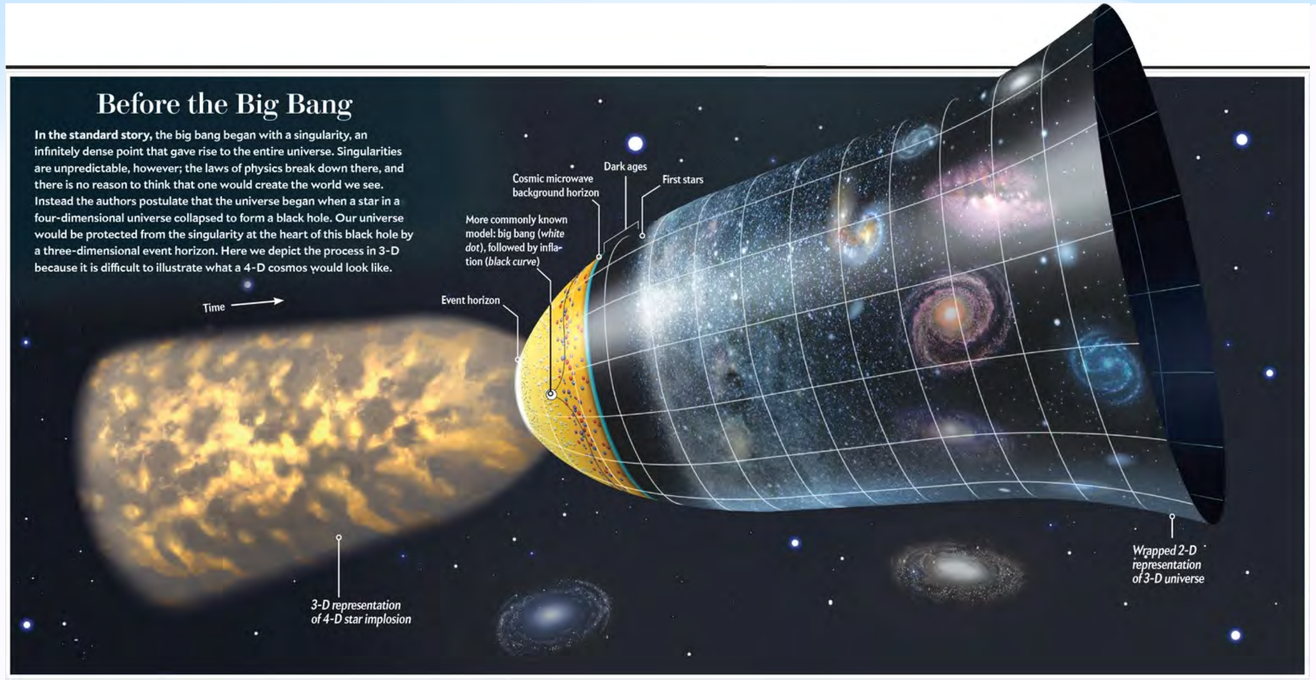
Answer Option	Number of Votes	Percentage
Cosmic Inflation	34	44 %
Bouncing or Cyclic Universe	6	8 %
Some quantum gravity model	12	16 %
Breakdown of Lorentz Invariance	1	1 %
Not inflation but don't have an alternative	10	13 %
Other	5	6 %
No Opinion	9	12 %
Total	77	100 %

9. *Big Bang*

In your opinion, how should we understand the Big Bang?

- ☐ An absolute beginning of time with a singularity at its start
- ☐ An absolute beginning of time without a singularity
- ☐ A theory that says the universe evolves from a hot dense state that says nothing about whether there was an absolute beginning of time or not
- ☐ Other
- ☐ No opinion





Only majority opinion!

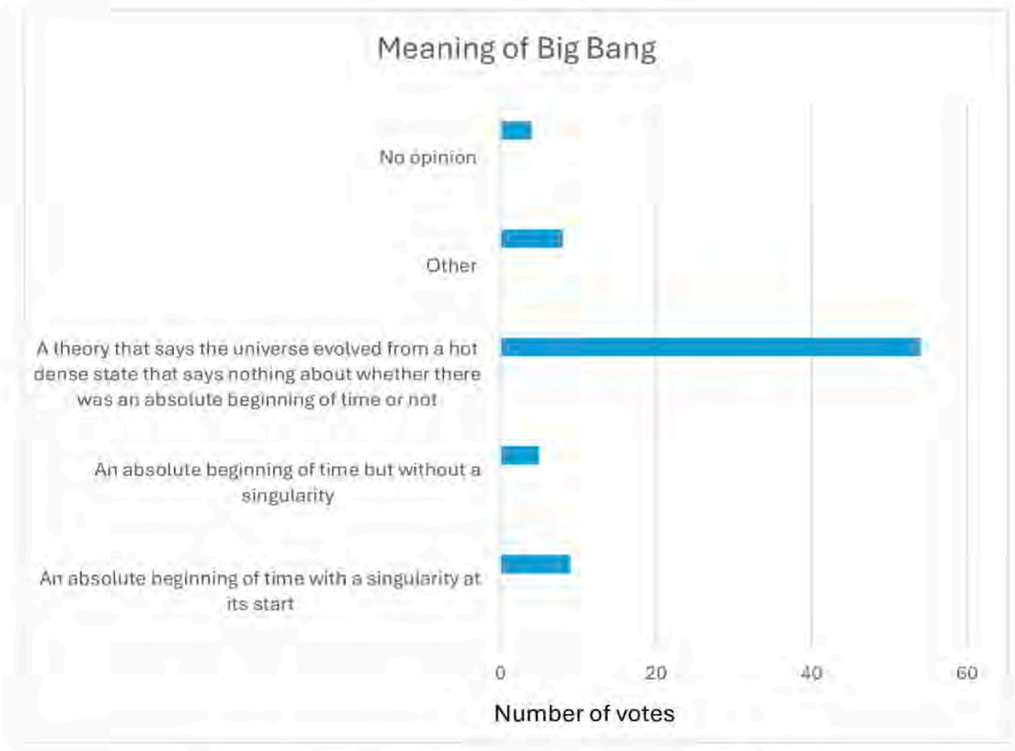


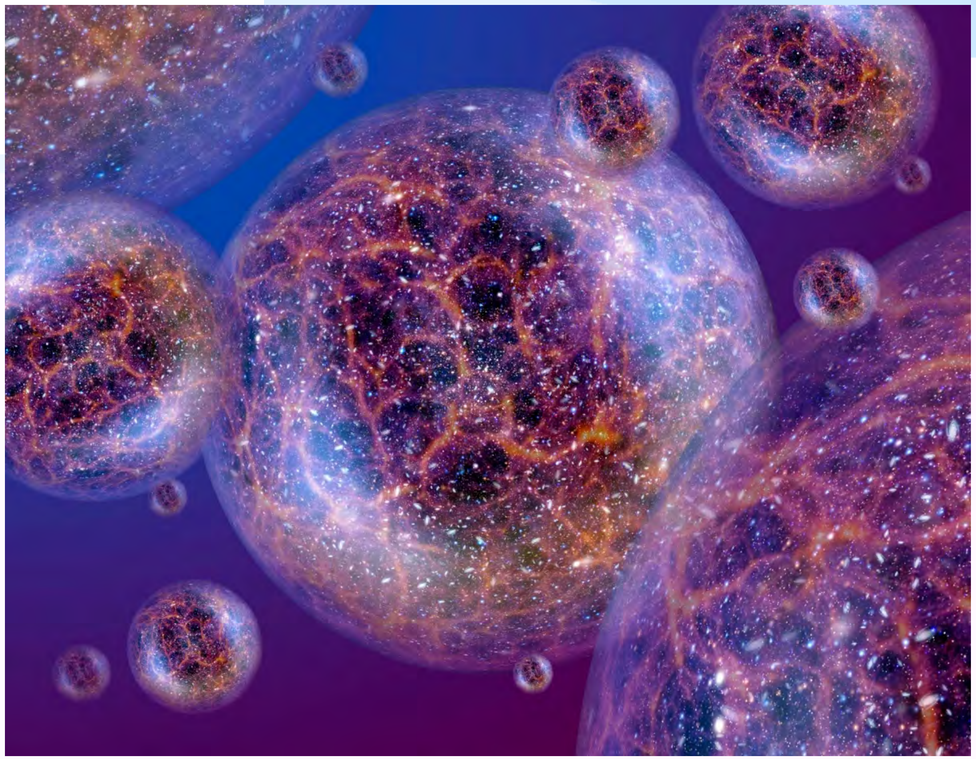
Figure 9: In your opinion, how should we understand the Big Bang?

Answer Option	Number of Votes	Percentage
An absolute beginning of time with a singularity at its start	9	11 %
An absolute beginning of time but without a singularity	5	6 %
A theory that says the universe evolved from a hot dense state that says nothing about whether there was an absolute beginning of time or not	54	68 %
Other	8	10 %
No opinion	4	5 %
Total	80	100%

10. Anthropic Coincidences

In your opinion what explains the values of physical constants of nature and the claimed anthropic coincidences?

- ☐ The values of the constants are set by necessity
- ☐ They are brute facts or need no further explanation
- ☐ Explained by anthropic selection in a multiverse
- ☐ Explained by a Darwinian process occurring in the cosmos (e.g., baby universes inside black holes)
- ☐ Explained by an intelligent designer
- ☐ Other
- ☐ No opinion



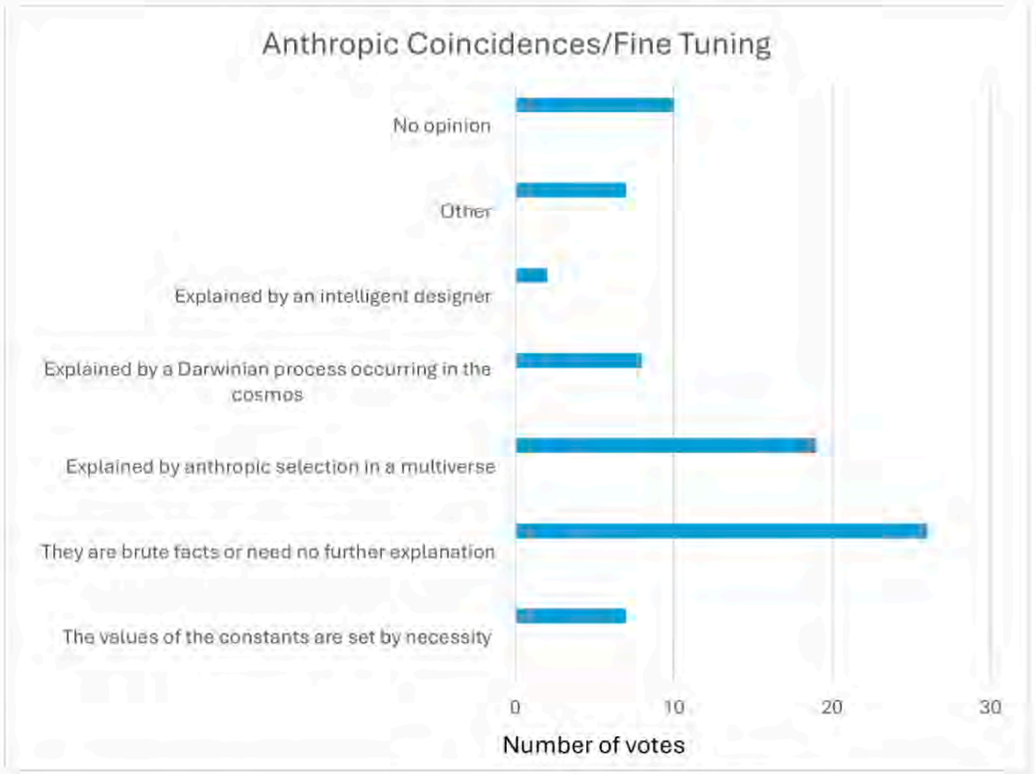


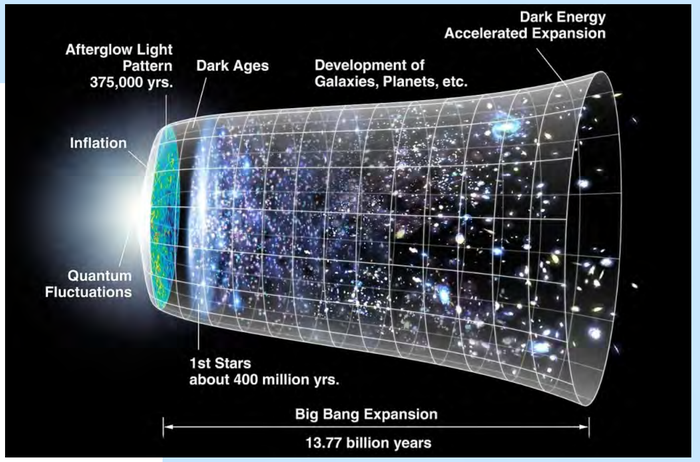
Figure 10: In your opinion, what explains the values of physical constants of nature and the claimed anthropic coincidences?

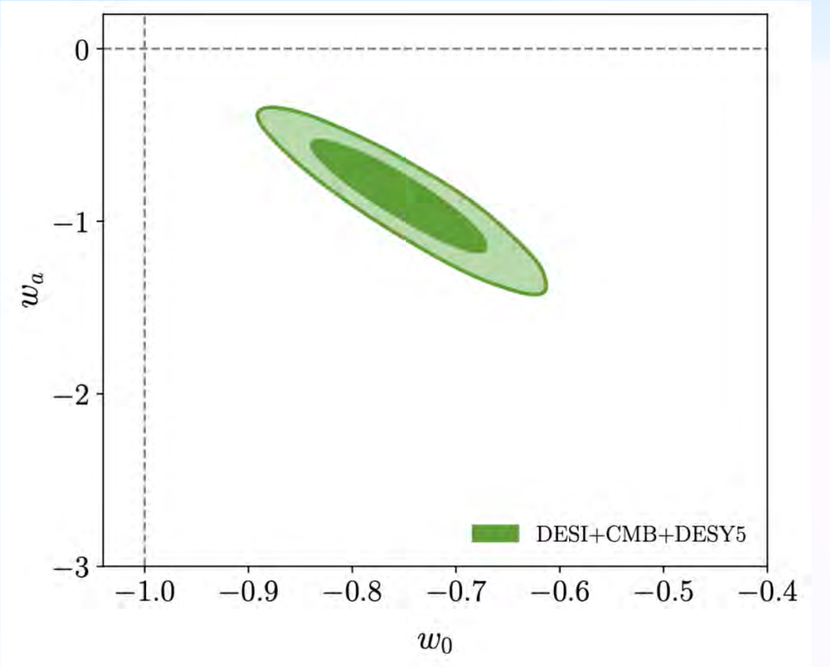
Answer Option	Number of Votes	Percentage
The values of the constants are set by necessity	7	9%
They are brute facts or need no further explanation	26	33%
Explained by anthropic selection in a multiverse	19	24%
Explained by a Darwinian process occurring in the cosmos	8	10%
Explained by an intelligent designer	2	3%
Other	7	9%
No opinion	10	13%
Total	79	100%

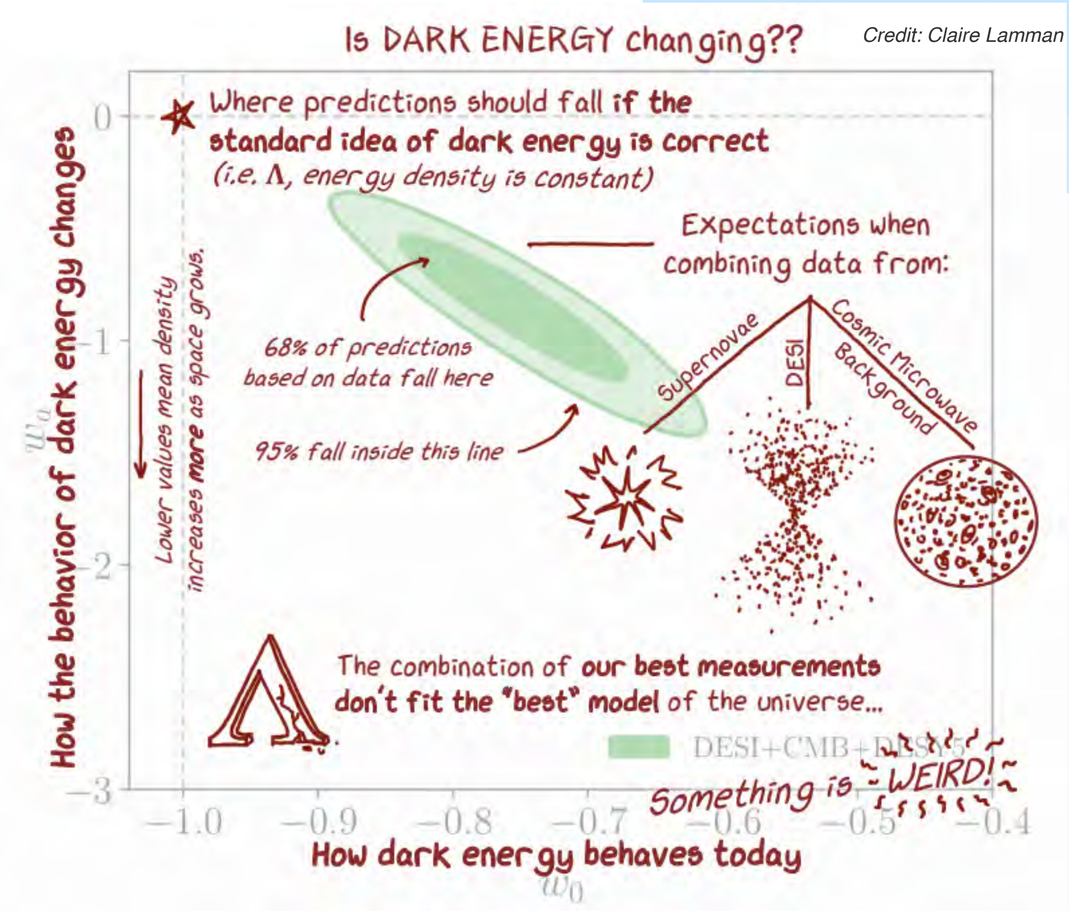
11. Dark Energy

In your opinion, what is the most likely candidate to be causing the universe to accelerate in its expansion?

- ☐ A cosmological constant
- ☐ A time varying field
- ☐ An effect of quantum gravity
- ☐ Some other modification to gravity
- ☐ Other
- ☐ No opinion







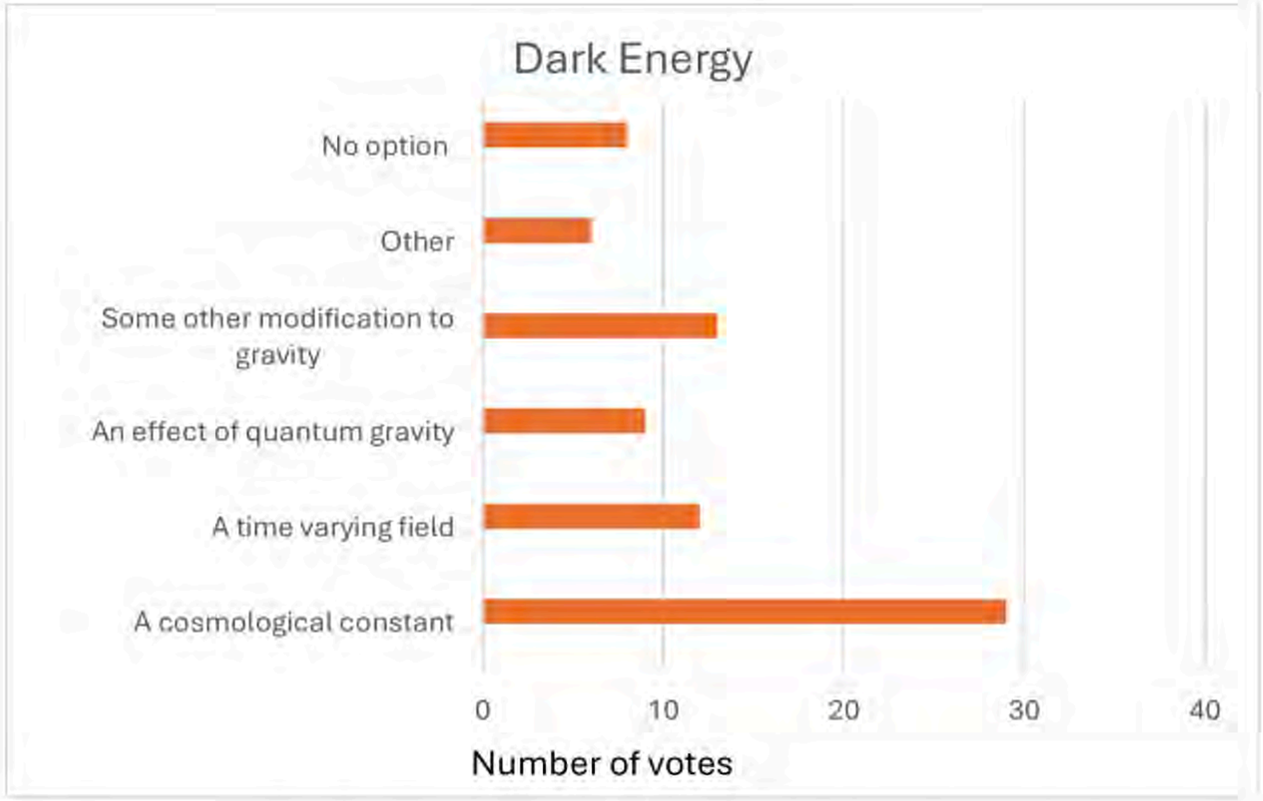
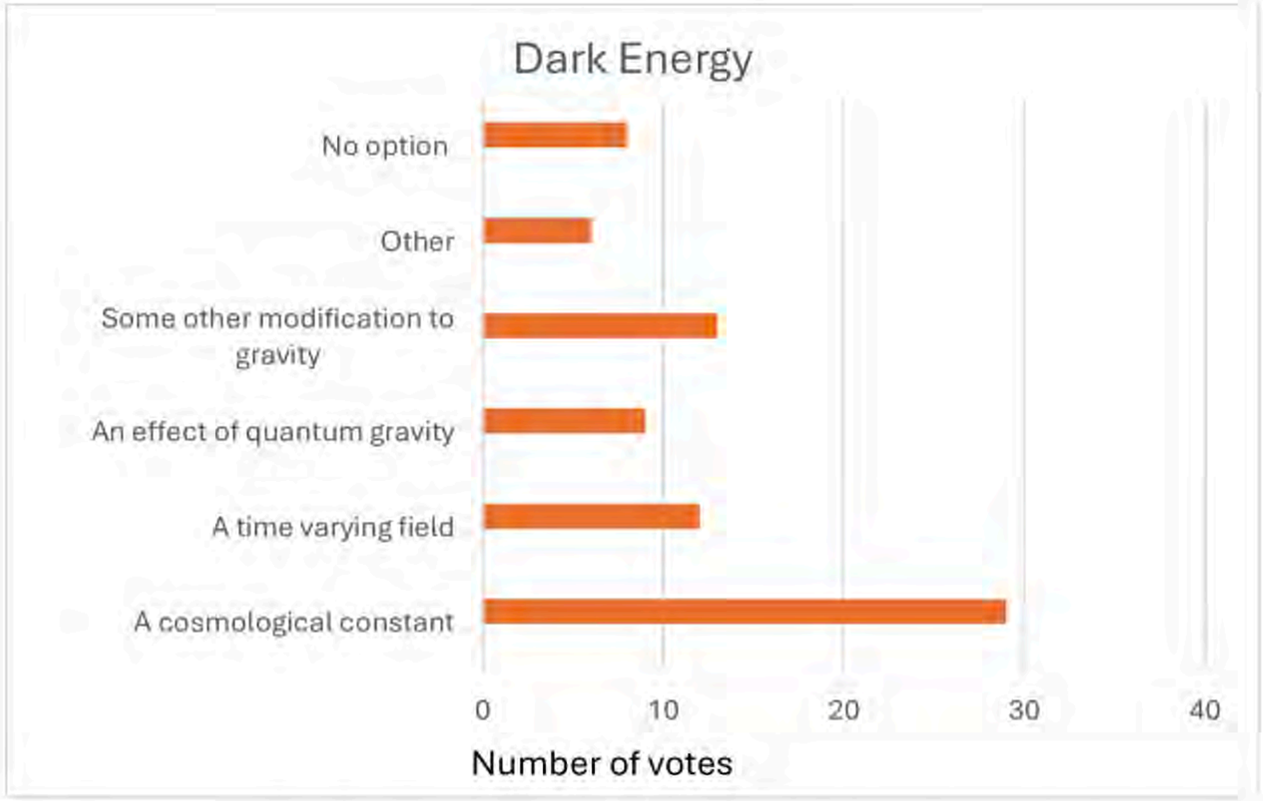


Figure 11: In your opinion, what is the most likely candidate to be causing the universe to accelerate in its expansion?

Answer Option	Number of Votes	Percentage
A cosmological constant	29	38 %
A time varying field	12	16 %
An effect of quantum gravity	9	12 %
Some other modification to gravity	13	17 %
Other	6	8 %
No option	8	10 %
Total	77	100 %



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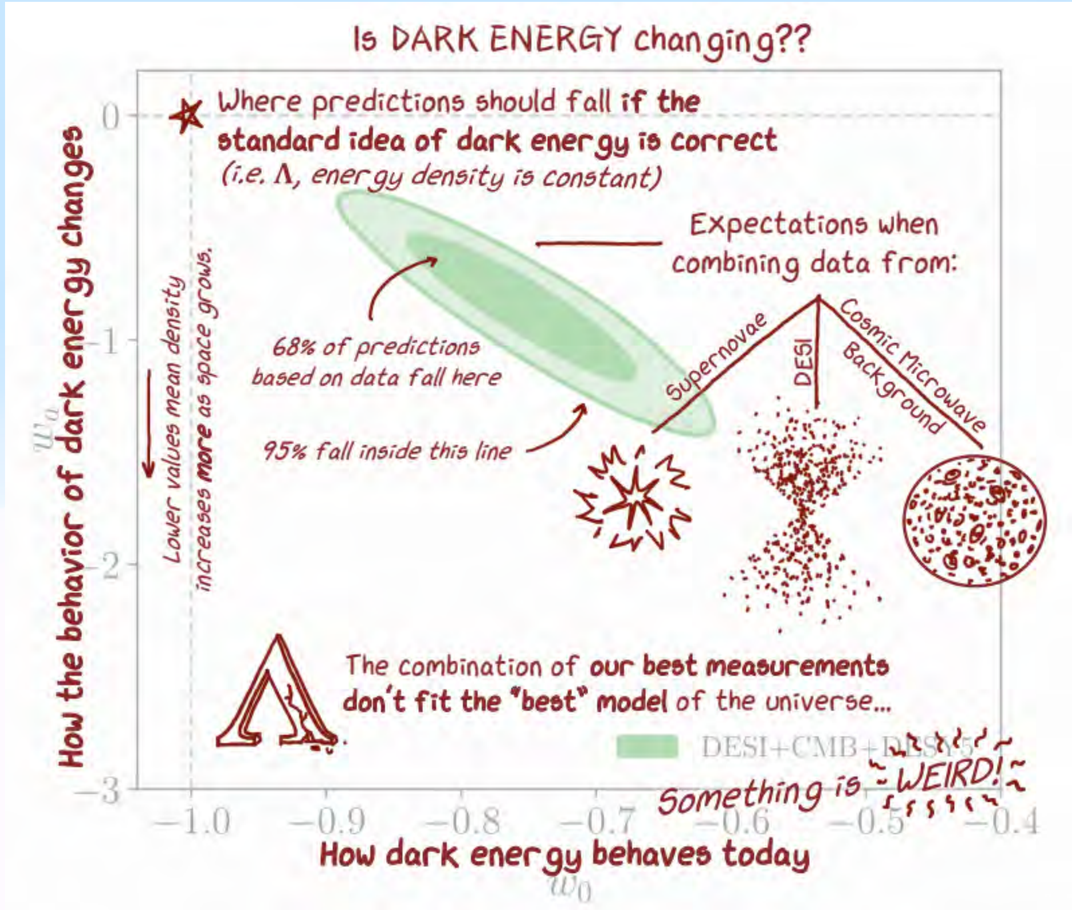
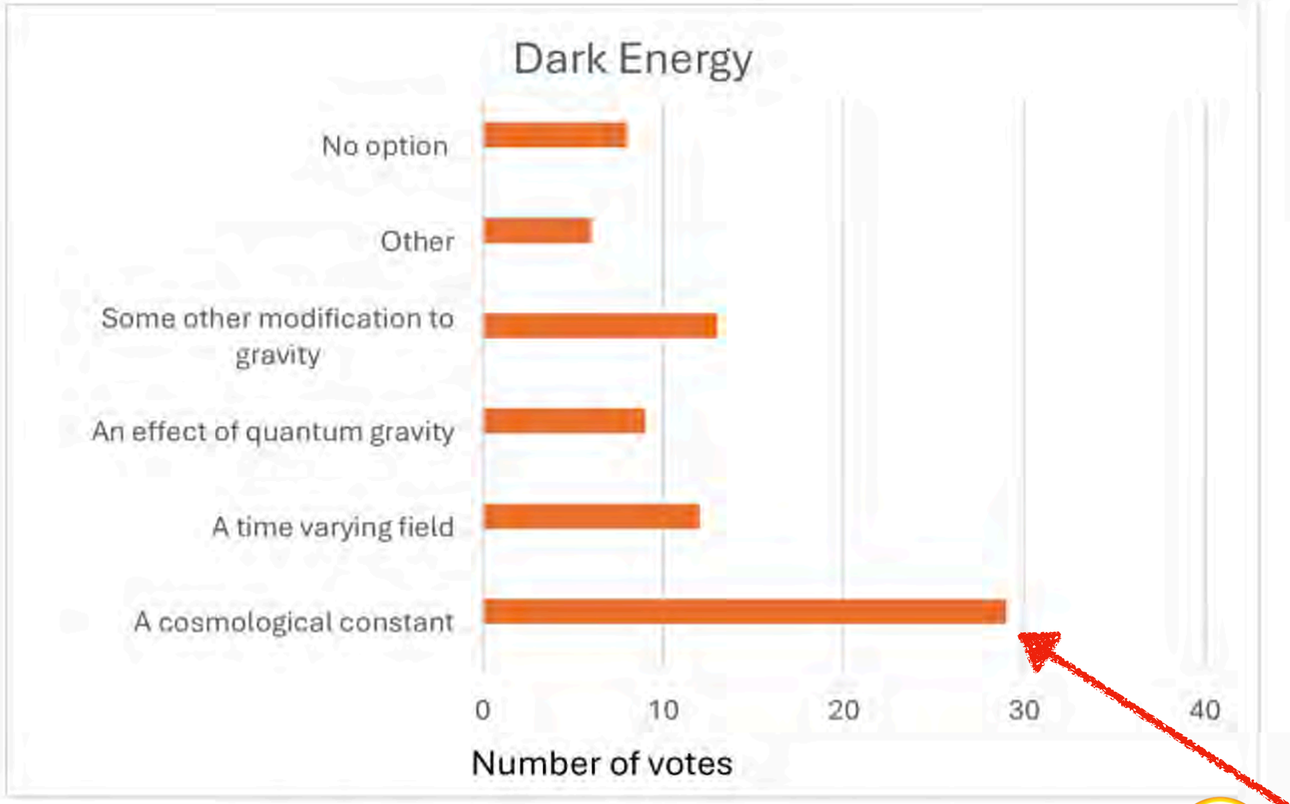
Other	6	8 %
No option	8	10 %
Total	77	100 %

from 8/2024 to 3/2025!



from 8/2024 to 3/2025!



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Other	6	8 %
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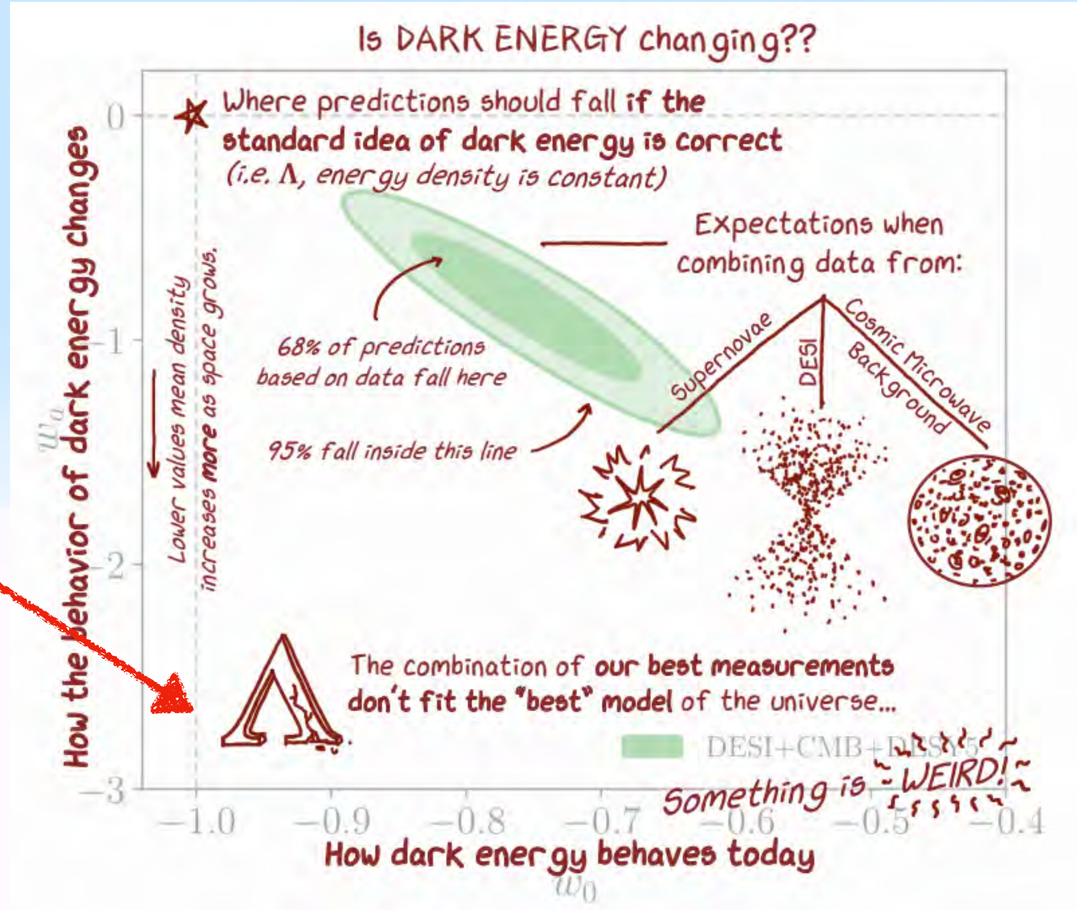
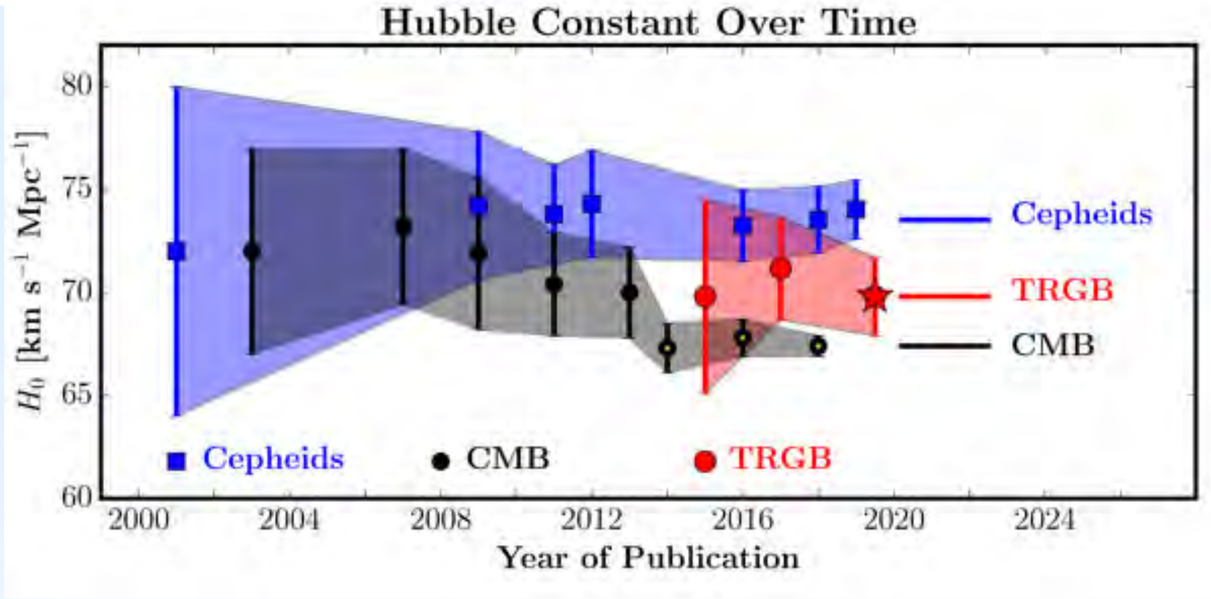
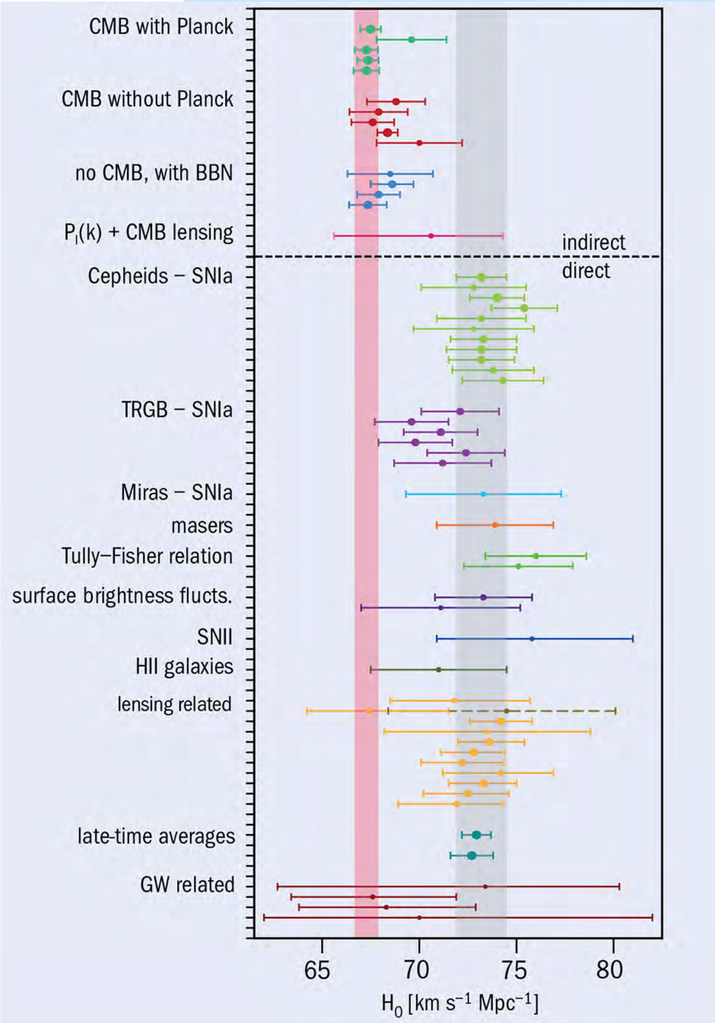


12. Hubble Tension

In your opinion, what is the most likely explanation for the Hubble Tension?

- ☐ Systematic errors in supernova data
- ☐ Systematic errors in CMB/Baryonic Acoustic Oscillations data
- ☐ Early dark energy
- ☐ Other new particles or fields
- ☐ Modified or quantum gravity
- ☐ Other
- ☐ No opinion





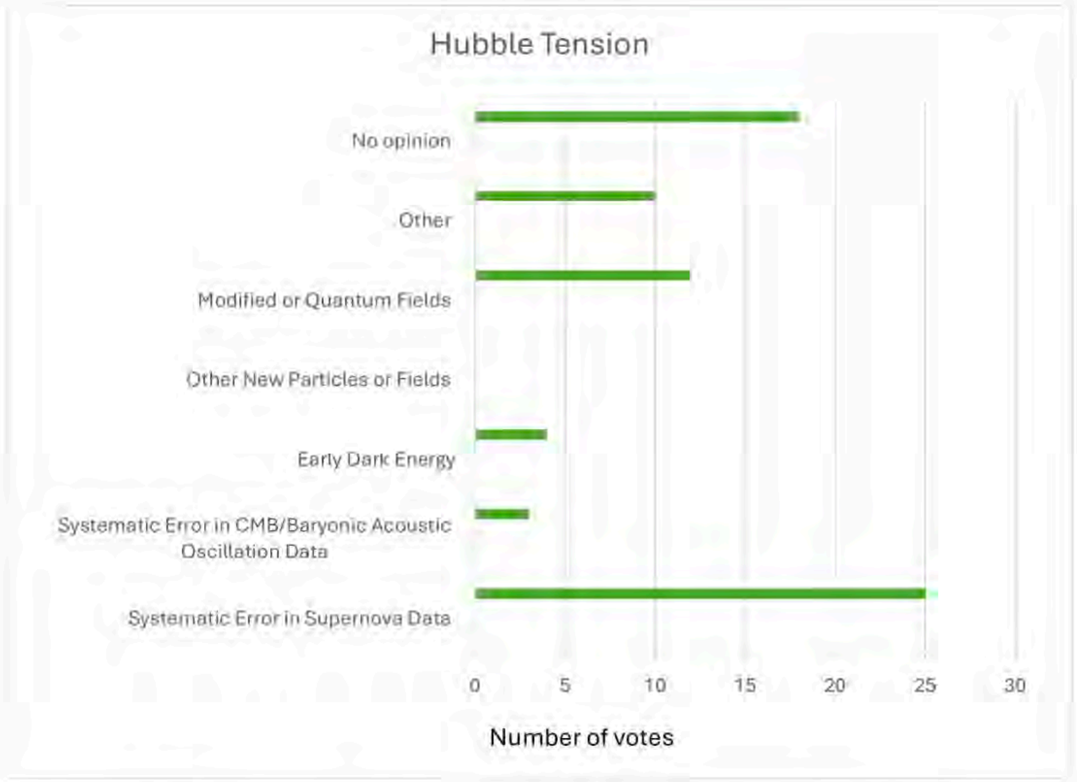


Figure 12: In your opinion, what is the most likely expansion for the Hubble tension?

Answer Option	Number of Votes	Percentage
Systematic Error in Supernova Data	25	35 %
Systematic Error in CMB/Baryonic Acoustic Oscillation Data	3	4 %
Early Dark Energy	4	6%
Other New Particles or Fields	0	0%
Modified or Quantum Fields	12	17%
Other	10	14%
No opinion	18	25 %
Total	72	100%

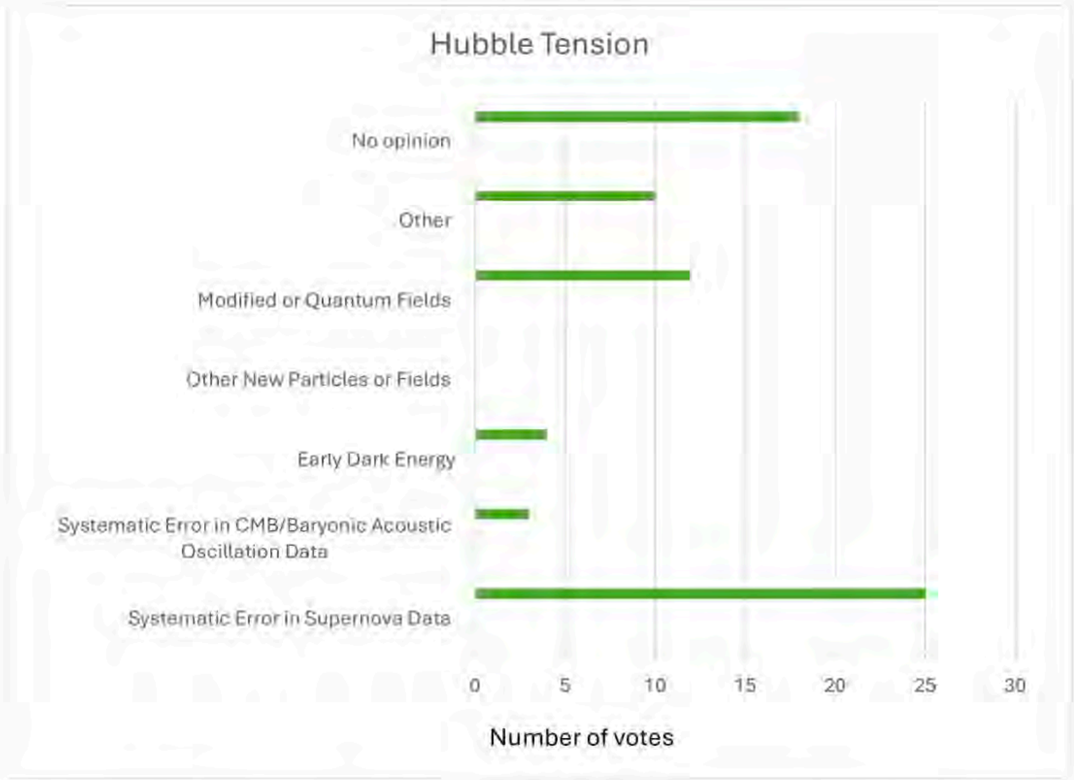
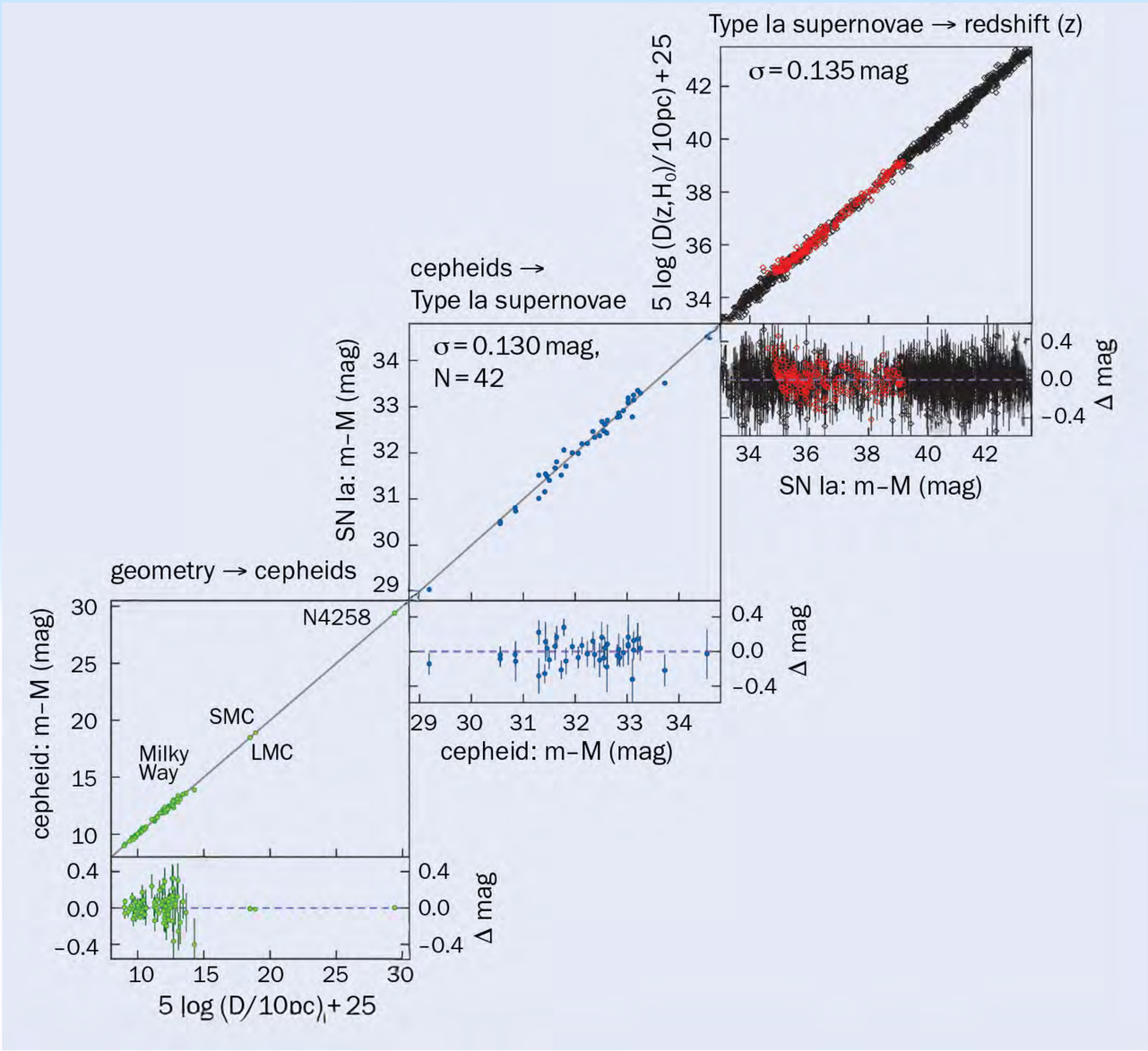


Figure 12: In your opinion, what is the most likely expansion for the Hubble tension?

Answer Option	Number of Votes	Percentage
Systematic Error in Supernova Data	25	35 %
Systematic Error in CMB/Baryonic Acoustic Oscillation Data	3	4 %
Early Dark Energy	4	6%
Other New Particles or Fields	0	0%
Modified or Quantum Fields	12	17%
Other	10	14%
No opinion	18	25 %
Total	72	100%



Conclusions

- Polling scientists does not decide the resolution of scientific controversies!
- Snapshot on consensus, or lack thereof.
- #papers ≠ consensus (e.g., resolving Hubble tension)
- Only majority approval (68%) for the statement: ***“The universe evolved from a hot dense state,*** **" *not* "*an absolute beginning time.”***
- ***Cosmological constant, cosmic inflation, or string theory*** < 50%
- No significant correlation (small sample size) ➡️ SOON APS? 🤞🏻
- Caution on describing ideas as consensus within the scientific community